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A MODIFICATION OF THE TEST OF MAXIMAL VOLUNTARY VENTILATION BASED ON THE RESULTS OF THREE EXPERIMENTS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "A Modification of the Test of Maximal Voluntary Ventilation Based on the Results of Three Experiments," submitted by Robin Ross Ryan in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The basic purpose of this thesis was to investigate the test of maximal voluntary ventilation (MVV), as it applies to males approximately twenty years of age with unobstructed pulmonary ventilation. The effects of different directives, respiration rate, and practice were sought in three experiments. The Douglas bag technique was used. Seventy-two subjects performed three twelve-second trials of MVV during each of three alternate-day sessions.

Treatment conditions varied in respect to breathing rates. These rates were either freely selected or prescribed and practised to metronome. Prescribed rates of 76, 112, 148 and 184 BPM were selectively assigned. All rates were registered using a Sanborn recorder and a pneumograph attachment.

Also investigated were: (1) intuitive rate in relation to optimal MVV; (2) 100 BPM as a mean optimal rate; (3) the validity of the "best" MVV of three trials in comparison to that of the mean; (4) optimal MVV breathing rate in relation to vital capacity; (5) comparison of MVV and vital capacity data with reported values; (6) correlation of physical characteristics with MVV and vital capacity, and comparison with reported values; and (7) smoker-nonsmoker differentiation on the basis of MVV and vital capacity. The subsequent intention was to suggest modification of the test of MVV where indicated.

Hypotheses inferred as being supported by the results of this study are: (1) The directive, "Breathe as deeply and as quickly as

you can!" is no more effective in achieving optimal MVV than the directive "Get as much air into that (Douglas) bag as you can!" ($P = 0.05$). (2) A subject caused to breathe faster than at a freely elected rate more closely approaches optimal MVV ($P < 0.05$, Sessions #1:2 and #1:3). (3) An intersession practice effect results from a series of MVV test sessions ($P < 0.05$, Sessions #1:2 and #1:3). (4) The mean optimal MVV breathing rate exceeds 100 BPM. (5) The largest minute volume recorded during three trials of MVV is no more valid an indication of that parameter than is the mean.

With respect to males approximately twenty years of age the principal modifications of the test of MVV assessed from this study are: (1) provision for the effect of practice by the administration of two test sessions of three trials each; (2) the calculation of the mean of the three trials, Session #2, to be observed as the MVV of the subject; (3) forceful demonstration to metronome prior to Trial #1 each session, without drawing attention to rate (indications were that demonstration should be at 120 BPM or faster); and (5) the recording of the breathing rate each trial. (If the mean, Session #2, is not within 146 $\pm$ 26.0 BPM, conduct a third session and direct the subject to breathe at a rate within these limits.)

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

There are two measures of respiratory ability extensively used to assess the efficiency of pulmonary as distinct from alveolar ventilation. These are provided by the forced vital capacity (FVC) maneuver and the test of maximal voluntary ventilation (MVV). Both are put to frequent use by clinicians endeavouring to ascertain the extent of ventilatory impairment due to disease. (The test of MVV is that which is still commonly referred to as the "test of maximum breathing capacity" (MBC), introduced by Hermannsen (23) in 1933.)

The dynamic nature of the test of MVV is sufficient reason that both exercise physiologist and physical educator should subject it to thorough examination.

The physiological components of this maneuver, and the respective conditions that must exist for each in order to achieve extensiveness of minute volume, are: (1) an extremely well integrated and coordinated neuromuscular system to regulate the amplitude and speed of volume change of the chest bellows; (2) maximal effort of strong respiratory musculature; (3) a patent tracheo-bronchial airway; and (4) normal elasticity of lung tissue. Consequently the test of MVV should hold implications for the fields of exercise physiology

and physical education.

Clinicians, in their numerous investigations of the test of MVV, have sought basically to: ascertain the apparatus, techniques and procedures that provide most valid and reliable results; establish norms of MVV for normal subjects so that the extent of patient impairment might be assessed; and correlate values of MVV to various categories of lung volumes and ventilatory measurements. Unfortunately in most of these studies there has not been adequate provision for the needs of correct experimental design and statistical technique. Many of these clinical experiments compare the performances of respiratory patients to those of unimpaired control subjects. The latter invariably ventilate markedly larger minute volumes. The possibility then that the test of MVV may distinguish between widely divergent levels of cardiovascular-respiratory fitness in an unimpaired population becomes an interesting speculation.

Stuart and Collings (38) compared the MVVs of physically conditioned and sedentary university students. They found no significant differences between the groups. However a significant difference might have been obtained using different experimental technique.

Preliminary testing by this investigator led to further scepticism regarding the efficacy of the traditional test of MVV. Consequently a critical examination of the test became the major undertaking.

Basic Purpose of the Study

The principal objective is to assess the effectiveness of the traditional test of maximal voluntary ventilation by experimental manipulation of three pertinent variables: instruction; respiration rate; and practice.

These factors are investigated as follows: (1) the motivational effectiveness of the standard instruction, "Breathe as deeply and as quickly as you can!"; (2) the effect on obtained values of MVV when breathing rates provided are both free and variously prescribed and practised to metronome at 76, 112, 148 and 184 breaths per minute (BPM); and (3) the practice effect of conducting test sessions on three alternate days. A logical outcome of this study is a modification of the traditional test of maximal voluntary ventilation.

Subsidiary Problems

The secondary objectives of this study are:

1. The investigation of a notion expressed by Ogilvie et al. (34:104) that a subject intuitively performs a test of MVV at a respiration rate which provides maximal minute volume.

2. The examination of the recent and relatively untested view (3,4,34) that a breathing rate of 100 BPM provides largest values of MVV.

3. The determination of whether the traditional practice of considering the largest minute volume recorded during three trials of MVV provides any more valid a measure of the parameter than does the

mean score.

4. The investigation of differences in vital capacity in relation to optimal rates of MVV.

5. The comparison of sample estimates of vital capacity and MVV (the latter obtained from two different treatment conditions) with those for the same sex and most comparable ages as recorded in the literature.

6. The correlation of age, height, weight, and body surface area (BSA) to vital capacity and MVV, and comparison of results to those in the literature.

7. The differentiation between the pulmonary function of smokers and nonsmokers in the sample chosen, on the basis of tests of vital capacity and MVV.

Hypotheses

The following hypotheses are investigated:

1. The instruction, "Breathe as deeply and as quickly as you can!" ("D&Q!") motivates a subject undertaking the test of MVV to a score that is not superior to that achieved under the instruction, "Get as much air into that (Douglas) bag as you can!" ("GMABC!").

2. The performance of a subject improves if he is caused to execute the MVV maneuver at a faster free rate than that at which he elects to breathe during an initial test session.

3. There is an intersession (between) practice effect associated with the test of MVV.

4. An untutored subject does not instinctively select the

breathing rate at which he achieves optimal minute volumes.

5. The mean rate at which subjects achieve optimal values of MVV is in excess of 100 BPM.

6. The largest minute volume recorded during three trials of MVV is no more valid a representation of that parameter than the mean volume.

7. Subjects with greater vital capacities achieve largest values of MVV at faster rates of respiration than do those with smaller vital capacities.

8. Nonsmokers demonstrate superior performance in tests of vital capacity and MVV than do those who smoke.

Delimitations

The scope of the study is delimited with respect to the following conditions:

1. Seventy-two second year, University of Alberta males provide the test data, eight more being tested in the event that replacement is necessary.

2. Only those parameters most pertinent to the investigation of the problems enumerated are closely scrutinized.

Limitations

In drawing inferences from the results of this study particular respect is due the following limitations:

1. The intra- and inter-individual differences associated with the level of subject motivation during the test of MVV are high.

2. The minute volumes and breathing rates calculated from twelve-second tests of MVV are subject to magnification of times five the observational error.

3. The acquisition of subjects by telephone communication is a procedure that restricts the randomness of the test sample.

4. The achievement of specific breathing rates during MVV is only moderately reliable when the maneuver is not performed to metronome.

5. The reliability with which the experimenter can manipulate the valve regulator with accurate timing in order to make a correct assessment of gas flow to and from the Douglas bag, is subject to human error.

6. In Experiment #2 and #3 the instruction, "Get as much air in that (Douglas) bag as you can!" ("GMABC!") was given instead of the customary, "Breathe as deeply and as quickly as you can!" ("D&Q!"). This change was based on the hypothesis that the former effects equally large or greater minute volumes. (Although this proposition was investigated in Experiment #1, the results were not available prior to the commencement of Experiments #2 and #3.)

7. Provision has not been made for smoker-nonsmoker differentiation in processing data, with one exception, in which case the performances of the two groups are compared.

Terms, Symbols and Definitions

For purposes of this study the following terms, symbols and definitions have been adopted (see Table I:1). This selection was

necessary due to duplication found in the literature. The terms "maximal voluntary ventilation" and "maximum breathing capacity" are examples of this confusion. Further evidence of difficulties experienced with terms, symbols and definitions is provided by Gandevia and Hugh-Jones (18:293) who state:

> As test results depend on the circumstances in which the test is performed, measurements intended to estimate MBC may vary; thus the term MBC was reserved to describe the theoretical maximum for a subject. A term was then sought to cover the various tests employed in estimating the MBC, the circumstances of the test being indicated by appropriate qualifications. The term "maximum ventilation" was favoured by many because it avoided the use of the word "volume"; the concept of volume in this connection is anomalous, in that the result is expressed in litres per minute. Unfortunately the abbreviation for maximum ventilation (MV) is the same as that for minute volume, and this was therefore rejected. Objection was taken to the use of "maximum voluntary ventilation" in that, if the circumstances of the test were strictly controlled the test was in some degree not voluntary. This was on the whole, overruled, and the term was finally adopted.

Apart from assessment of vital capacity, all testing in conjunction with the study is of maximal voluntary ventilation either free or controlled. The latter is subject to an important distinction. The difference, which applies to half of the total treatment conditions, is that the subject (1) observes a demonstration of MVV to metronome set at a specific rate; (2) practises passively at that rate under the same conditions; and (3) endeavours to perform the test of MVV at the same rate from memory. Thus, the last step in the procedure is clearly different from that which is normally adopted.

The connotation of "controlled" rate in this study is not that of precise adherence to the cadence of a metronome. Instead, it is the influence of practice prior to a test, and limited by the ability

of the subject to recall that given rate. The reason for following this procedure is to ensure that the subject is not distracted from the basic task of performing maximal minute ventilation through any concern for maintaining a rigid specified rate of breathing.

TABLE I:1

TERMS, SYMBOLS AND DEFINITIONS PERTAINING TO THIS STUDY*

Standardized Term	Symbol	Definition	Previously Used Term
Cardiovascular-respiratory fitness		The ability of the cardiovascular and the respiratory system to adjust to successive levels of work intensity. The most objective criterion for evaluating this circulatory and respiratory adaptability is the level of maximal oxygen consumption (2:676).	
Vital capacity	VC	Maximal amount of gas that can be expelled from the lungs following a maximal inspiration.	
Forced vital capacity	FVC	The vital capacity performed with expiration as rapid and as forcible as possible. (A combination of definitions: (8:97) and (18:290).)	Timed vital capacity; fast vital capacity; fast maximal expiratory capacity
Forced expiratory volume (subscript indicates the interval in seconds from start of expiration to when volume is measured (wording modified))	FEV_T	Volume of gas exhaled over a given time interval during the performance of a forced vital capacity (e.g.: $FEV_{1.0}$ is the forced expiratory volume in one second).	Timed vital capacity; fast expiratory capacity; forced expiratory capacity; maximum expiratory volume.

* Each unacknowledged description is attributable to Boren et al. (8) in 1966.

TABLE I:1 (Continued)

Standardized Term	Symbol	Definition	Previously Used Term
Maximal voluntary ventilation	MVV	Amount of air which can be breathed with voluntary maximal ventilatory effort per unit of time (expressed in litres per second)	Maximum breathing capacity; maximal breathing capacity; maximum ventilatory capacity
Test of maximal voluntary ventilation	Test of MVV	The subject breathes (a) as deeply and as quickly as possible or (b) as deeply as possible at a controlled frequency, both tests being performed over a specified period of time (twelve seconds in the case of this study). The former version, in which neither frequency nor depth are controlled, is termed "maximal voluntary ventilation, free" (MVV_F), the frequency that is adopted by the subject being noted thus: MVV_{F40}; MVV_{F60}. For the latter version, in which frequency is controlled, the rate used is indicated thus: MVV_{40}; MVV_{60}. (Gandevia and Hugh-Jones (18:291)).	Maximum breathing capacity test
Maximal breathing capacity	MBC	The largest of all maximal volumes of gas which can be breathed per unit of time by any available method, whether it be a test of MVV_F or MVV "controlled", or a test performed after the subject has exercised or inhaled carbon dioxide gas. The term is reserved to indicate a theoretical maximal value for a given subject (from a consideration of discussion by Boren et al. (8:97), Gandevia and Hugh-Jones (18:293), and Comroe (10:209)).	Maximum breathing capacity

CHAPTER II

REVIEW OF THE LITERATURE

There are some concurring indications in the literature that two fundamental aspects of the test of MVV should be further investigated with a view to increasing its validity. These are:

1. Where the purpose of conducting the test is an endeavour to appraise MBC, a rate of breathing elevated beyond that which was previously conceived (5,6,14) to yield optimal minute volumes appears to be more valid (3,4,34).

2. Apparently there is a learning factor (17,28) from one session to another that is not presently provided for in accepted test procedure (10,19).

Even such indications as these have conveyed little impact, as evidenced by the test remaining unmodified.

Why has so much research upon the test of MVV not provided more knowledge?

The Problem of Test Variables

One source of difficulty is the considerable number of test variables capable of a significant effect. Some of the most important are as follows:

1. Resistance to flow varies from an assembled test apparatus in one laboratory to that in another. Consequently, inter-study comparisons of results are strained (10:210).

2. The technician's influence varies within and between studies in quality of instruction, personal demonstration and motivational effectiveness (12:418).

3. The duration of a trial and the time between trials vary from study to study. (Consider the implications of comparing minute volumes of MVV in different investigations when the duration of the trials was: thirty to sixty seconds (23); twenty seconds (21); and twelve seconds (35).)

4. Age, height, weight and body surface area tend to vary in a test sample; and there is varying evidence of significant correlations between MVV and these items, as provided by Boren _et al_. (8:104).

5. The extent of impairment differs from one ventilatory condition to another, and one patient to another.

6. The patient may not cooperate, having such just or unjustified motives as fear, avoidance of pain, or the achievement of compensation (26:73).

The existence of a large number of variables each capable of a significant effect leads to such individual differences in apparatus, procedure and technique, that Wright (in a comment following Comroe (10:213)) expressed the opinion that, "The condemning lack of uniformity deserves great emphasis."

Standardization of the Test of MVV

The need for standardization has been fully recognized. Such authors as Comroe (10:210) and McKerrow (31:532) have advanced views

and suggestions. Gray et al. (21:680), in reference to a table of normal values of MVV determined by various investigators, are frank in their appraisal:

> Aside from the variability of results, the lack of previous standardization of the method is also revealed in the table. Some investigators have failed to take the marked sex difference into account; none appear to have allowed for the learning factor. Very few have corrected their values to BTPS.

To the inexperienced observer the test of MVV appears most uncomplicated, but this is not so.

The present study departs from conformity in that a twelve-second trial of MVV is administered rather than the accepted fifteen (10:209). The justification is that during preliminary testing the performance of healthy unobstructed subjects appeared to wane over the longer interval. Pease (35) and Stuart and Collings (38) also preferred twelve-second trials.

Experimental Problems

Despite the problem of test variables as discussed, it appears that research of this ventilatory ability has not provided an improved test because it has been generally deficient in regard to statistical design and analysis.

From a clinical viewpoint, the precision of the test is only as important as the ability of the observer to differentiate between clinically normal and abnormal subjects on the basis of test scores. However, if a subsequent intention is to attempt differentiation between normal subjects (and this would seem worthy of investigation, as discussed in the introduction) an exceedingly sensitive test would

appear necessary.

A further problem is the term "maximal voluntary ventilation" (see Table I:1), for reasons other than those expressed by Gandevia and Hugh-Jones (18:293), referred to in Chapter I of this thesis. The connotation of "maximal" is such that the word does not appear to belong in the term if it is to be used in reference to a patient with a pulmonary condition. However, obstructed subjects may be considered to produce maximally under their existing debilities. As an example, the use of bronchodilator drugs (9:211) affects MVV. Consequently, the term MVV is relative to the individual.

Apparently limitations associated with clinical studies have hampered progress in the understanding and application of MVV as defined, in a non-clinical orientation. One such limitation pertains to the rate, or range of rates, at which breathing during the test provides an accurate assessment of MVV. Miller et al. (32) tested unobstructed subjects and patients with ventilatory insufficiency. They observed that there was considerable variation in the breathing rates at which supposed MBC was achieved, beyond the sixty-five BPM minimum that they instructed subjects to attain.

The optimal rate, or range thereof, of breathing during the test of MVV has likely continued to be understood as being slower than it actually is. The obstructed patient undoubtedly experiences difficulty during the performance of the test, which has definite implications for the rate of breathing adopted. This in turn affects the minute volume. Consequently it would appear that the researcher

and the technician have instituted slower rates than would otherwise have been established. Donald (12:418) provides a reason as follows:

> There may be some risk in pulmonary tuberculosis and other chronic infections such as bronchiectasis, that the highly unnatural and relatively violent respiration will cause aspiration of actively infected material into healthy lung tissue.

Modification is completely understandable in these circumstances. However, there is a definite departure from the definition, which suggests that it, in turn, should be modified for clinical use and the sake of general clarity. Subsequently, clinical experimentation involving both respiratory patients and unimpaired control subjects has been designed so that essentially moderate breathing rates cater for the debility of the patient, the control subject being encouraged, unconsciously or by design, to perform at a slower rate than that at which he may perform optimally. A study by Miller et al. (32:512), in which obstructed patients performed free-rate MVV at 45-120 BPM, supports this argument. Also, an obstructed group investigated by Ogilvie et al. (34:103), performed at free rates, 18-66 BPM. In contrast, Bartlett and Specht (4:80) reported that laboratory personnel had little difficulty in performing the test of MVV at 196 BPM.

It appears distinctly possible that generalizations have been made regarding the optimal rate, or rates of breathing for normal unobstructed subjects, from a consideration of data for control subjects in clinical studies (a point illustrated later in this review). Appraisal of data for unobstructed subjects would appear to be of questionable validity if performed without due respect for context. Further apparent limitations are: (1) the influence on rate, as

discussed; and (2) experiments being designed specifically to research obstructed pulmonary function.

Motivation in Relation to Reliability

Motivation is repeatedly acknowledged as having a significant bearing upon the performance of MVV (1,10,12,13,23).

Bartlett and Specht (4:80), investigated the effect of contrived inspiratory and expiratory resistances upon the MVVs of three laboratory personnel aged 20-49 years, and observed that:

> Due to the subjective, voluntary nature of the test, each determination need not represent the best effort. In fact, when upwards of eighty tests are made during a single day (as was the case) a maximum effort for each test becomes increasingly difficult.

This is a limitation in experimental procedure that might have reflected markedly upon motivation and consequent reliability of performance. Such was not observed from the data by the authors, however.

Comroe (10:210) stated that, "The subject must desire to cooperate to the point of exhaustion," and that he ". . . must be urged continually and emphatically during the test . . . ." In contrast, Friend (17), examining the effect of a series of test sessions, chose not to provide instruction, demonstration or exhortation after the first day. The mean minute volumes for subsequent test sessions were reported, nevertheless, as being significantly greater ($P < 0.001$).

Breathing Rate and the Validity of the Test of MVV

Several investigators (3,4,34) have found that increased rate of breathing improves the validity of the test of MVV. A study by Kennedy (26:77) in which the MVV of obstructed miners and potters was tested yielded results to the contrary. The author found that minute volumes in excess of 60-70 LPM were provided by breathing rates, 40-60 BPM.

Practice in Relation to Reliability

Gray *et al*. (21) in a normative study of maximal voluntary ventilation, used healthy aviation cadets, medical students, technicians and female nurses, as subjects. The effect of learning was also investigated. All subjects performed three trials within a ten-minute interval during a first session, and many repeated the test a week later.

In regard to the practice effect during the first session, a 12 per cent increase in minute volume was observed from the first to the second trial, and 4 per cent from the second to the third ($r = 0.790$). Respective means for the fourth and fifth trial during the second session a week later were not appreciably different from one another. Similarly, their combined mean was only 4-5 per cent greater than that for the second and third trial combined mean. (Tests of significance were not reported.)

In subsequent investigations, Matheson *et al*. (28,29) chose to discard the results of the first trial in the test session and consider the combined mean of the second and third as a representative

value. In a similar undertaking, Matheson and Gray (28) tested the MVV of a group of medical students of mean age, 23.3 years (SD:3.4), and reported a combined mean minute volume for the second and third trial during the first session of 160.9 LPM (SD:19.5), compared to 168.6 LPM (SD:19.2), during the second session. Again, a test of significance was not performed. However, the results suggest the possibility that there might be a learning effect from first to second session.

Bartlett and Specht (4), in an experiment employing inspiratory and expiratory resistances to testing MVV (previously referred to in this review), also assessed the effect of learning upon intra- and inter-session scores. The results were negative.

Friend (17) sought the same learning effect in two separate experiments involving medical students of combined mean age, 23.1 years (range: 19-31). He found that (1) during the first session the mean of second trial scores was significantly larger than that for the first and third trials ($P < 0.001$ and $P < 0.002$ respectively, using a t-test); and (2) the group mean for the three trials on the second day was significantly larger than that for the first day ($P < 0.001$, also using a t-test).

Intuition and Optimal MVV Breathing Rate

On the basis of mean scores of MVV recorded at free rate and 40, 60, 80 and 100 BPM to metronome, Ogilvie et al. (34), in studying normal and emphysematic subjects, observed that ". . . most of the subjects voluntarily breathed at the rate most favourable for shifting

the maximum volume of air."

Comroe (10:210) subscribes to the view that the subject intuitively performs at the optimal rate for best minute volumes, in advocating that the subject be permitted to choose his own rate and depth of breathing. Bernstein and Kazantzis (6:328) are opposed:

> The subject is assumed in some unknown way to find the best combination of depth and rate of respiration which affords the highest value for this minute ventilation. Now there is really no reason a priori to assume that this is the case.

In reference to a pilot study they had completed, D'Silva and Mendel (14:325) said of the instruction, "Breathe as deeply and as quickly as you can!"

> Not only was there a wide variation in the rate chosen by different subjects, but the same subject chose different rates at different attempts.

This experience does not suggest any intuitive guidance in the matter of optimal breathing rate, and consequently minute volume.

One Hundred BPM as the Rate for Optimal MVV

Bartlett et al. (3) observed two subjects perform MVV to metronome at various levels of breathing rate, ranging 20-200 BPM, and recorded largest minute volumes at approximately 100 BPM. The only results provided were graphed, and indicated to this author that values were slightly larger at 120 BPM, though not significantly.

Earlier, in collaboration with Specht, Bartlett (4:82) reported that for the lowest resistance used during both inspiration and expiration, MVV was largest for the three subjects at metronomed rates of 60-120 BPM. However, in extrapolating MVV at 140 BPM on the graph provided, it appears that there is little to distinguish between

volumes collected at 64, 98, 120 or 140 BPM, subject to the same conditions of minimal resistance.

Considering the limitations of the experiment, notably: (1) the small number of subjects (three); (2) the considerable range in age (20-49 years) and weight (140-175 pounds); (3) the effect of lengthy test sessions on motivation; (4) the stepwise sequence of breathing rates to which the subjects were exposed; and (5) individual differences that might have been expected in optimal rates, it appears that there is little justification in attempting to establish that the small mean differences obtained were significant.

Ogilvie et al. (34), in an investigation of the MVVs of unobstructed normal subjects and emphysematic patients, had them all perform to metronomed rates of 40, 60, 80 and 100 BPM, as well as at free rate. From the data they concluded that largest MVVs were obtained at approximately 100 BPM, which is misleading because rates in excess of 100 BPM were not investigated. This result, they claim, confirms the findings of Bernstein et al., who in fact state (5:261):

> Our highest values for the MVC (MVV) were obtained at 70 RPM (BPM). Increasing the rate to 80 RPM did not significantly alter the MVC, and though it is possible at greater respiratory rates the MBC would remain the same or might continue to rise, we have made too few observations to reach a conclusion on the point. As our highest values for the MVC were obtained at 70 RPM we regard this rate as the lowest at which the true MBC is reached.

Stuart and Collings (38:508) subsequently cite Bartlett and Specht (4) and Ogilvie et al. (34), in a ventilatory study of athletes in training and sedentary medical students (referred to in Chapter I) when they state that, "A respiration rate of 100 BPM is considered optimal during this test." A difference between the MVVs of these two

treatment groups might well have existed but been masked by the adopted rate of 100 BPM; perhaps 100 BPM was too slow.

In further reference to Ogilvie _et al_. (34), it is notable from their results that when twenty-four normal subjects performed the test at free rate of respiration, eight exceeded 100 BPM (mean rate: 128), and six of the eight surpassed the volumes they attained performing to metronome set at 100 BPM. The mean score at the 100 BPM setting for these eight subjects was 121 LPM, and it increased by sixteen LPM under the free-rate condition.

At free rate of respiration (mean: 96.6 BPM) there was a 6.6 LPM mean increase beyond the 140.3 LPM scored at 100 BPM to metronome. And of those who elected to breathe at rates slower than 100 BPM, seven scored less and four scored more than when they breathed in cadence to metronome at 100 BPM. What would have occurred had all subjects chosen a free rate in excess of 100 BPM?

As discussed earlier, a normal subject is capable of performing at a free rate of his own selection that extends to 200 BPM. Thus, considering the data in the study by Ogilvie _et al_. (34) it would appear that the results could have been quite different had the other sixteen subjects also chosen to breathe at a free rate in excess of 100 BPM. Therefore the decision by these authors that largest MVVs occur at about 100 BPM, is questionable.

"Best" Performance Versus Mean

Gray _et al_. (21:679) express the problem aptly:

> It is common procedure to take the best rather than the mean score on the principle that the true capacity cannot be less than

> that actually scored. However this procedure neglects the important fact that extreme values are least representative of the thing measured.

These observations were made on the basis of experimentation by the authors (discussed earlier in this review, in relation to the effect of practice upon performance). It was noted then that they chose to dismiss the first trial as practice, and consider the mean of the second and third trial because of the superior values obtained during these trials.

Gray and Green (22) consider that the existence of random errors of measurement is ignored in electing to process largest scores of MVV rather than the means. Comroe (10) advocates two trials, and that the larger value be considered as representative of the MVV. This, of course, is not consistent with the reasoning of Gray *et al.* (21:679) as given. Kory *et al.* (27) and Boren *et al.* (8), in two major pulmonary function studies, relate in detail the procedure used to test MVV. However, they neglect to specify whether the mean or the "best" value was selected.

If, as Gray *et al.* (21) report, there is a sizeable practice effect evident from the first to the second trial, but there is little to choose between the second and third attempt in a test session, then it appears that the mean value of the second and third trial (as the authors advocate), or perhaps the largest value, would be more representative of MVV ability than the mean of all three trials.

Reliability of the Vital Capacity

Tests of vital capacity were performed in addition to those of

MVV. Both are accepted tests of static and dynamic lung properties respectively.

In 1846 Hutchinson (25) produced an extensive biometric treatise on vital capacity. The quality of the study was such that the results are still cited. One negative outcome however was that it established the concept of vital capacity as being a constant quantity. This concept still exists as is evident from such a statement as the following (7:296):

> Spirometers were designed and used originally for the measurement of metabolic rate or such respiratory constants as vital capacity.

Gilson and Hugh-Jones (19:205) point out that vital capacity fluctuates according to circulatory changes in the lungs. They tested male subjects, aged 29-65 years (mean age: 41.3) in various stages of pneumoconiosis, and recorded three trials of vital capacity. Means for successive trials were 3.71, 3.73, and 3.72 litres respectively. Standard deviations were not provided, but on the basis of the equality of these means there was not considered to be an effect due to learning or fatigue.

Matheson *et al*. (29), using medical students and nurses of combined mean age, 24 (SD: 4 years), recorded a correlation coefficient of 0.97 for two successive trials on a given day, and 0.98 when the trials were one week apart.

On the basis of these studies the test of vital capacity would appear to be very reproducible, and not noticeably affected by the circulatory changes referred to by Gilson and Hugh-Jones (19:205).

Vital Capacity in Relation to MVV Breathing Rate

One of the hypotheses investigated in this study is that a subject with a greater vital capacity achieves a larger minute volume at a higher rate of respiration. There is no recorded physiological basis to this proposition, nor any reference to it in the literature. It was an impression gained during preliminary testing. Were this hypothesis to be supported in the course of this study, it would suggest that Stuart and Collings (38) might well have found a significantly greater mean MVV for a group of athletes (as opposed to that of a group of medical students) if both groups had been encouraged to breathe at rates faster than 100 BPM. (The mean vital capacity of the athletes was significantly greater than that of the medical students. ($P < 0.05$, using a t-test).)

Normative Values and Pertinent Correlations

As the second year university students to be tested in this study were expected to be about twenty years of age, normative values for this age level were sought in the literature.

Male sub-groups within six studies are summarized in Tables II: 1-3, the first five being such that means, standard deviations, and age-height-weight-BSA correlations with MVV and VC provide information for ordered mean ages, 15-25 years. In the sixth study, by Goldman and Becklake (20), a distinctly older age-level was investigated. Although this latter study was performed at altitude 5,760 feet the authors did not detect that values were significantly different from those recorded at sea level.

Statistics for two groups within studies by Needham et al. (33) and Stuart and Collings (38) are also provided in Tables II: 1-3.

The reasons for the increased mean scores of MVV reported by mean height and weight of their test subjects were greater than those of other test groups; (2) test trials were conducted over twelve seconds (only Boren et al.(8) reported an equally short duration); and (3) the Douglas bag technique was employed (by Needham et al. (33) also, but the others used a spirometer).

Only the mean MVV obtained by Boren et al. (8) approaches the means for the athletes and sedentary students tested by Stuart and Collings (38). However, Boren's subjects had a distinct age advantage.

Pease (35), tested the maximal voluntary ventilation of high school students (age range: 15-17 years), and reported a mean value of 146 LPM (SD:21.3). This result compares with that of Needham et al. (33) shown in Table II:1. However, the subjects exposed to the Pease experiment were volunteers from physical education classes. Therefore the respective samples are probably not comparable.

In regard to correlations of body characteristics to MVV, Pease (35) found that the MVV-weight correlation was nonsignificantly contrary to the findings of Needham et al. (33) (see Table II:3). However, he found that height and BSA correlated significantly with MVV at the 0.001 level of confidence.

Gray et al. (21), tested the MVV of adult male and female subjects in respiratory health and reported that they were unable to establish any useful degree of correlation between MVV and any of the

TABLE II: 1

MEANS AND STANDARD DEVIATIONS FOR MVV AND VC, IN CERTAIN SELECTED STUDIES

Author	N	MVV		VC		Nature of Sample
		Mean	SD	Mean	SD	
Needham et al. (33)	78	103.0	32.0	3.45	0.98	Participants in youth groups, and army recruits (aged: 11-19 years)
	16	136.5		4.56		Those from the above group, aged 18 and 19 years
Gray et al. (21)	89	167.8	22.1			Aviation cadets
Stuart and Collings (38)	20	192.0	32.0	5.29	0.75	Medical students assessed as sedentary during a two-year period
	20	197.0	32.0	5.69	0.67	Conditioned athletes: matched by age, height, weight and BSA with the above group
Boren et al. (8)	115	184.0	29.0	4.82	0.65	Patients and staff in fifteen hospitals; no signs of lung or heart disease
Baldwin et al. (1)	17	126.0	28.6	4.01	0.62	Hospital patients: no signs of lung or heart disease; sub-group (16-34 years)
Goldman and Becklake (20)	44	137.6	38.66	4.44	0.88	Hospital staff and relatives

TABLE II: 2

BODY CHARACTERISTICS OF SUBJECTS IN SELECTED MALE STUDIES OF MVV AND VC

Author	N	Age		Height		Weight		BSA	
		Years	SD	Cm	SD	Kg	SD	M^2	SD
Needham *et al.* (33)	78	15.3	2.60	160.5	14.48	50.98	12.84	1.51	0.27
		(Ages: 11 to 19 years)							
	16			176.3		66.23		1.82	
		(Part of the above group; ages, 18 and 19 years)							
Gray *et al.* (21)	89	20.9	2.54	176.9	6.53	72.80	6.58	1.88	0.11
Stuart and Collings (38)	20	22.7	2.34	181.4	6.60	76.20	8.16	1.97	0.14
		(Sedentary group)							
	20	20.6	1.30	181.6	6.35	76.61	10.93	1.97	0.13
		(Athletes in condition: matched age, height, weight and BSA with the previous group)							
Boren *et al.* (8)	115	25.1	2.70	176.0	7.62	75.75	12.70	1.91	0.17
Baldwin et al. (1)	18	25.5	6.00	173.8	8.60	66.00	8.30	1.77	0.14
Goldman and Becklake (20)	44	44.3	16.60	173.9	7.22	74.60	11.80	1.89	0.16

TABLE II: 3

CORRELATIONS OF MAXIMAL VOLUNTARY VENTILATION AND VITAL CAPACITY WITH PHYSICAL CHARACTERISTICS, IN SELECTED MALE STUDIES

	Needham *et al*. (33)	Stuart and Collings (38)	Stuart and Collings (38)	Baldwin *et al*. (1)	Goldman and Becklake (20)
Number of Subjects	78 All 11-19 years	20 Sedentary	20 Athletes	52 Note: all males	44
Maximal Voluntary Ventilation with					
Age	0.83			-0.63	-0.79
Height.	0.84	0.46	0.35	0.41	0.33
Weight.	0.89	0.43	0.45	0.27	0.24
Surface Area. .	0.90	0.46	0.48	0.36	0.31
Vital Capacity with					
Age	0.86			-0.43	-0.67
Height.	0.89	0.65	0.46	0.49	0.62
Weight.	0.91	0.68	0.44	0.23	0.32
Surface Area. .	0.93	0.73	0.49	0.44	0.46

various body characteristics. Consequently no correlations by these authors appear in Table II:3.

Smoking, As It Affects MVV and Vital Capacity

With senior Air Force Officers aged 38-57 years as subjects, Hensler and Giron (24) submitted habitual smokers and nonsmokers to a battery of ventilatory tests. An unspecified type of spirometer was used in testing MVV. Age, height, and weight, means and standard deviations, were strikingly similar.

Pertinent to the present study, the results as indicated by a chi-square analysis were that the pulmonary function of the nonsmokers was significantly superior to that of the habitual smokers in respect to the test of MVV ($P < 0.001$) and the vital capacity ($P = 0.004$). The authors stated:

> In all respects the smokers display abnormal values significantly more frequently than do nonsmokers ($P < 0.01$), although there is no significant difference demonstrated with increased consumption of cigarettes (24:887).

In a study of U.S. Army veterans, Boren et al. (8) investigated those who smoked in excess of twenty cigarettes per day, and nonsmokers. Respective values recorded for MVV were 160 LPM (SD:31.0) and 169 LPM (SD:34.0). The authors allowed that the age discrepancy may have accounted for some of this difference (smokers: mean age, 40.3 years; nonsmokers: 35.8 years).

Similarly, with regard to vital capacity, nonsmokers with mean VC, 4.77 litres (SD:0.85) registered superior performances in comparison to the smokers with mean VC, 4.68 litres (SD:0.63). Again, age was suggested as a significant factor.

The effects of both smoking and intensive athletic conditioning upon ventilatory mechanics were investigated by Shapiro and Patterson (36). The test groups consisted of nonsmoking, "superbly conditioned" members of the U.S. Navy Underwater Demolition Team; nonsmoking sedentary hospital corpsmen; and clinically normal seamen who smoked regularly.

In respect to MVV, means and standard deviation were: athletes, 173.6 LPM (SD:25.1); and smokers, 137.1 LPM (SD:24.2). Analysis indicated these means to be significantly different ($P < 0.001$), suggesting the combined effects of conditioning and smoking. A further analysis of the data for the smoker-nonsmoker sedentary groups indicated means to be significantly different ($P < 0.02$).

Finally, MVV differences between the nonsmoking athletic group and the sedentary nonsmoking corpsmen indicated as being nonsignificant, obscured perhaps by the age disparity being in favour of the sedentary. Respective means and standard deviations were 27.5 years (SD:5.7) and 20.8 years (SD:1.8).

Physical Condition in Relation to MVV and Vital Capacity

In studies by Stuart and Collings (38) and Shapiro and Patterson (36), both already discussed, conditioned athletes scored larger mean minute volumes of MVV than sedentary subjects, but not significantly so. However, each experiment had a noteworthy limitation as follows:

1. The former study involved practice and attempted performance at 100 BPM to the sweep hand of a wall clock, on the

questionable supposition that 100 BPM is the optimal rate for all subjects.

2. The latter study showed a minute volume advantage of approximately fifteen LPM in favour of a group of highly-conditioned underwater demolition men as opposed to comparatively sedentary hospital workers. This superiority could perhaps have attained a level of significance if the mean age of the athletes, 27.7 years (SD:5.7) had not put them at such a disadvantage to the comparatively inactive hospital corpsmen, 20.8 years (SD:1.8).

On the basis of these limitations, the implications of the level of cardiovascular-respiratory fitness to performance of MVV are therefore still open to speculation.

The athlete group in the Stuart and Collings study (38) had a significantly larger vital capacity ($P < 0.05$). However, Shapiro and Patterson (36) did not include a consideration of vital capacity in their study, so comparisons cannot be made.

Muscular Strength in Relation to MVV and Vital Capacity

With regard to the relationship between the strength of the specific muscles involved in MVV and the level of the performance achieved, McIlroy et al. (30) state that:

> Maximum muscular effort is expended and thus the rate at which respiratory work is done during the test is theoretically of importance in assessing the maximal effort of which the respiratory muscles are capable.

A further possibility that elements of speed, power and coordination of the respiratory musculature are of importance lies in the realization that MVV scores decline as subject age increases.

Baldwin (1:264) reported a significant coefficient of correlation of -0.633 ($P < 0.0004$) for MVV with age, upon testing hospital patients without evidence of pulmonary or cardiac disease. Ages ranged, 16-69 years (mean age: 42.9). For the same group the vital capacity-to-MVV correlation was significant at -0.432 ($P < 0.005$).

Obesity in Relation to MVV and Vital Capacity

Concerning the relationship of obesity to MVV and vital capacity, Sharp *et al*. (37) used a range of ventilatory tests upon normal subjects (to 208 pounds), obese normal subjects, and those with obesity hypoventilation syndrome.

Pertinent to a consideration of MVV, they found that respiratory resistance was somewhat increased in the obese. They also observed that the obese normal subjects scored total respiratory work values up to twice those for the normal subjects, times 1.3 being the average.

Respective mean MVV recordings for normal and obese normal subjects were: 156 LPM (range: 145-178) and 118 LPM (range: 99-129). Mean vital capacities in the same order were 4.28 and 4.03 litres. Recorded heights in both groups were very similar, but due to the age disparity larger values might have been expected for those categorized as normal. Their mean age was 35.8 years (range: 29-45) as compared to 40.2 years (range: 29-51) for the obese normal.

CHAPTER III

METHODS AND PROCEDURES

Sample

Eighty undergraduate males registered in their second year at The University of Alberta, during the 1966-'67 academic session, constituted the test sample. This group was intended as a random selection representative of their college year. Twelve subjects were assigned to each of two treatment groups in three separate experiments. The remaining eight were available as substitutes, and four were required.

The first twenty-four subjects were assigned alternately to the first and second treatment condition in Experiment #1. The next twenty-four took part in Experiment #2, their allocation to respective treatment conditions Day #2 and #3 being decided on the basis of matched mean MVVs for Day #1. Twenty-four more were then assigned to Experiment #3 and all exposed to the same treatment condition. The eight potential replacements were assigned two to each of the total of four different treatment conditions employed throughout all three experiments.

The Apparatus and a Description of its Use

The assessment of vital capacity. Expiratory vital capacity was performed using a Wedge spirometer (model 370), and the tracing was registered on photographic paper by an Electronics for Medicine recorder (see Figure III-i). The subject's nostrils were sealed with

a nose-clamp. A clean plastic jacket was placed around the mouthpiece for each subject. The volume exhaled into the spirometer was recorded at ambient temperature and pressure, saturated (ATPS), and later converted to body temperature and pressure, saturated (BTPS), in accordance with the literature. Temperature was read hourly from a Water's Corporation battery-operated thermometer (model TT-14). (During the study, ambient temperature ranged 23-26°C.) Barometric pressure was also obtained hourly, using a Princo standard mercurial barometer.

The measurement of MVV. The Douglas bag technique was used to assess MVV (see Figures III-ii to vi). The subject breathed into a Collins plastic Triple-J high velocity valve through a Collins rubber mouthpiece. The Triple-J valve was fitted to an eleven-inch section of rubber hose, one and one-quarter inches internal diameter (as was all tubing used in these MVV experiments). The other end of this section was attached to a two-way aluminum valve inserted in the neck of a suspended 100-litre Douglas bag. A quarter-turn clockwise of the two-way valve regulator permitted exhaled air to flow into the Douglas bag from the Triple-J valve. At the end of each trial the regulator was rotated as quickly as possible back to the original position. Thereby the subject was prevented from adding to the volume, and collected air was free to be evacuated. For this purpose a Collins vacuum pump with a rheostat control was used. It was connected to the valve by a twenty-six inch length of rubber hose. The volume of air so removed was measured with an American Meter Company dry gas meter

FIGURE 111-i. Subject performing a vital capacity maneuver by means of a Wedge spirometer (model 370).

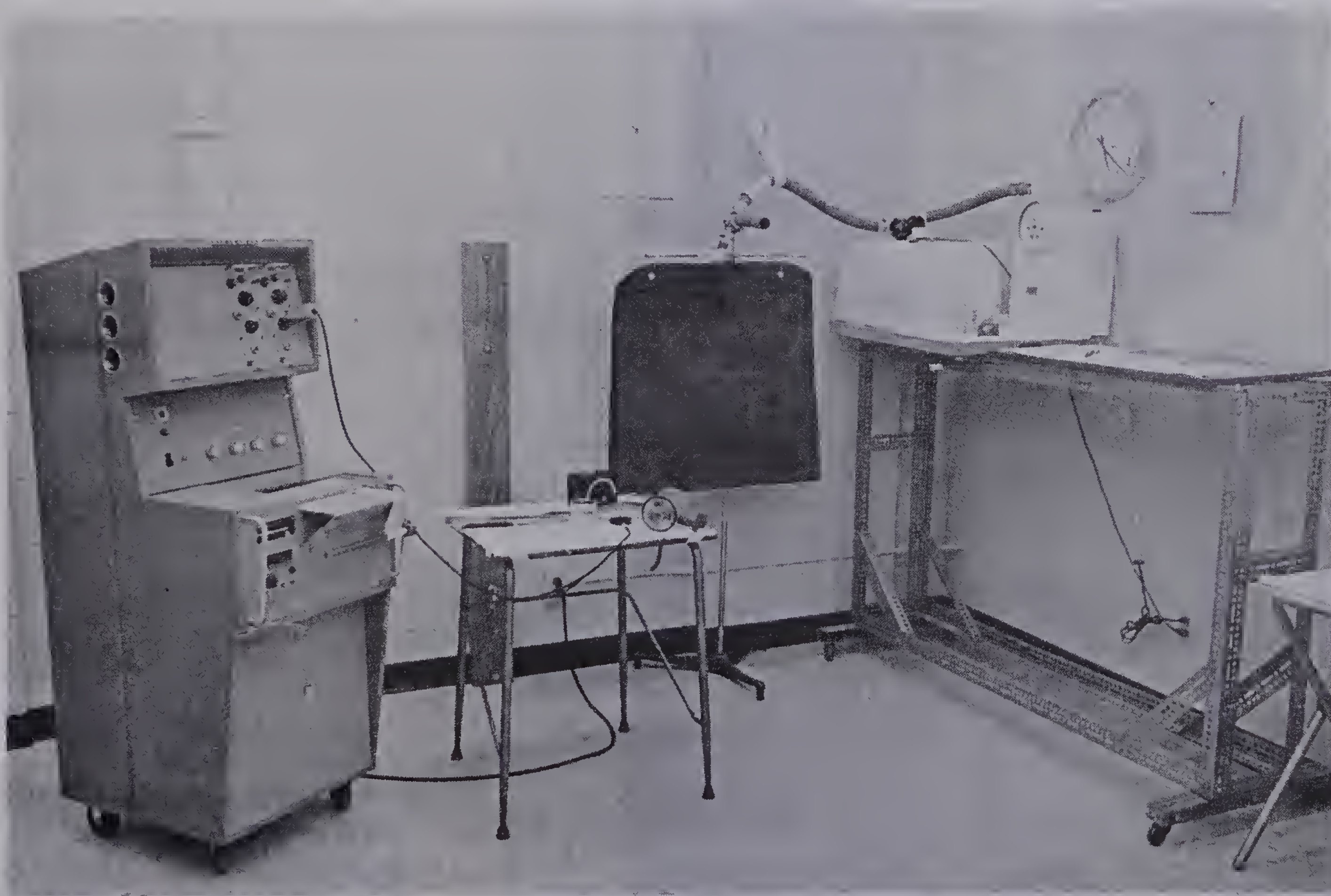

FIGURE 111-ii. The apparatus used in testing maximal voluntary ventilation under various treatment conditions.

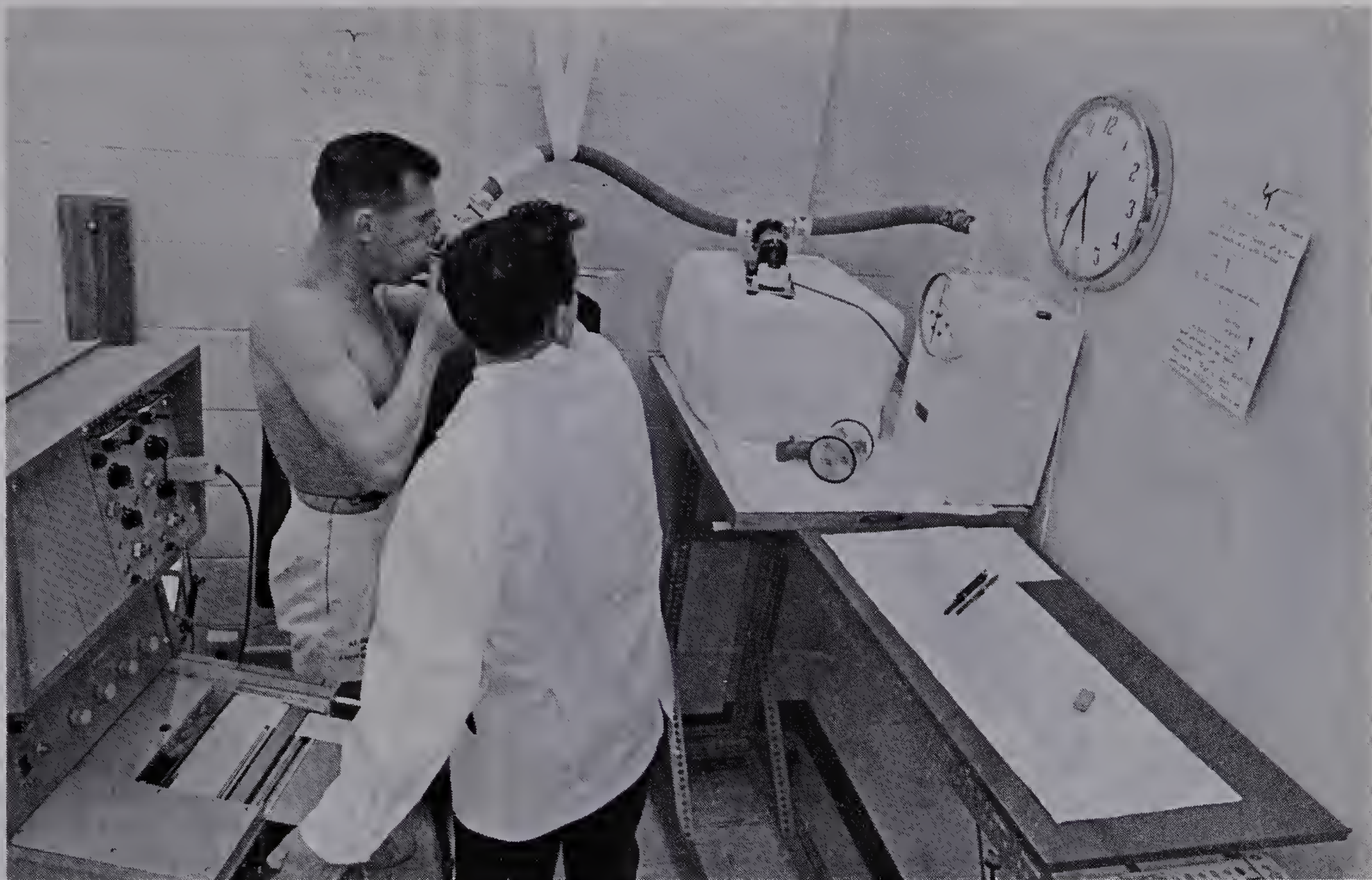

FIGURE 111-iii. A performance of the test of maximal voluntary ventilation. (The obscured right hand of the technician controls the valve regulator).

FIGURE 111-iv.

For visual accuracy in timing the test of MVV the technician is positioned as directly as possible before the clock.

FIGURE lll-v.

Electric wall clock with four alternative quadrants prepared for the timing of a test of MVV.

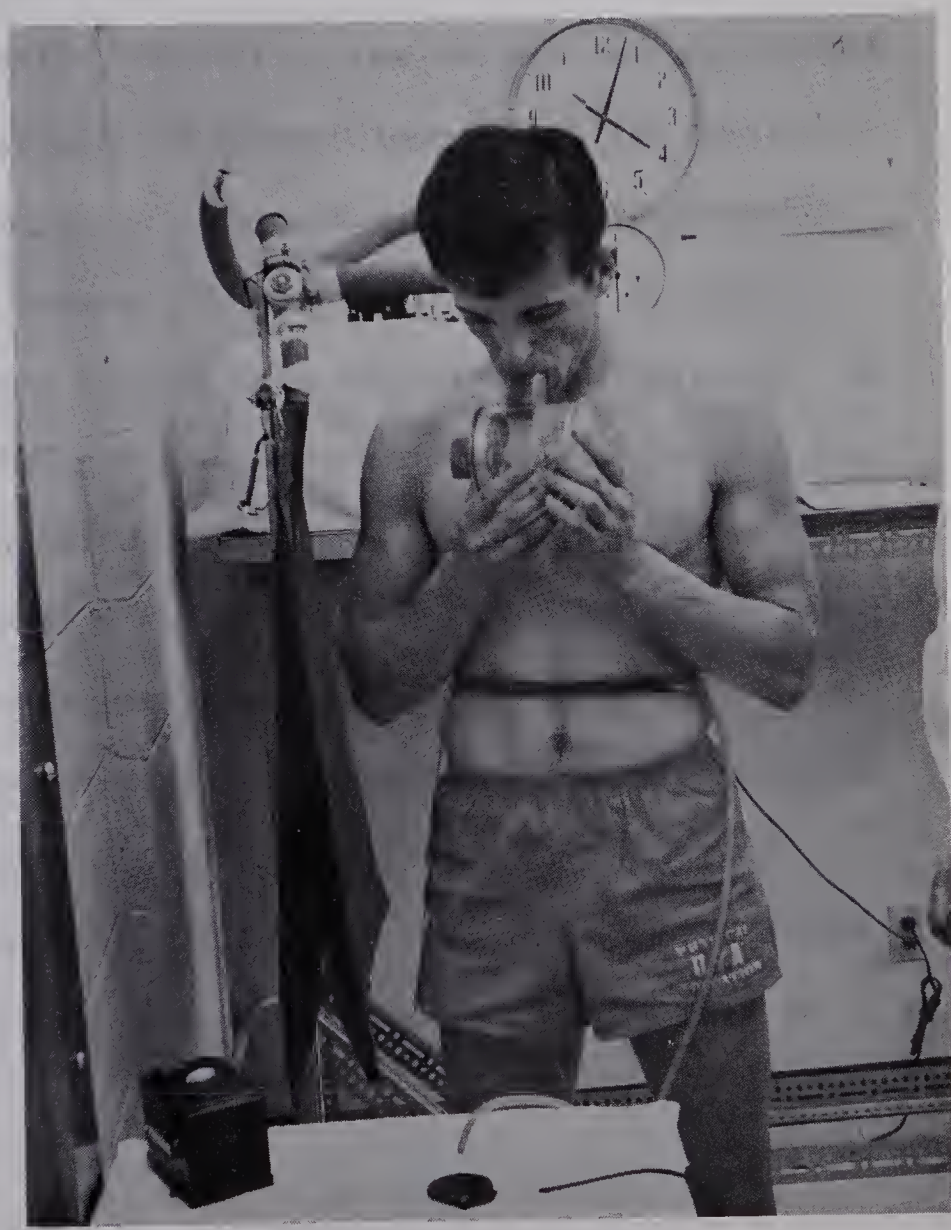

FIGURE lll-vi.

Subject practising at a prescribed rate of breathing set to metronome.

attached to the pump by a fifteen-inch section of rubber tubing.

The recording of respiration rate. Respiration rate was recorded for all trials of MVV. Around the subject at the level where the tapering rib cage meets the external oblique muscles of the abdomen, a Sanborn pneumograph attachment (model 108) was secured. This device, coupled to a Sanborn pulse wave attachment (model 374), enabled respiration rate to be detected. Impulses were recorded using a Sanborn four-channel recorder (model 964). The following standardized procedures were adopted:

1. The Sanborn recording paper was set in motion at twenty-five millimetres per second during a three-second countdown preceding each twelve-second trial of MVV.

2. On the instruction, "Go!" (for the subject to commence the trial) the technician depressed the remote timer switch for twelve seconds and effected a continuous time-marker signal to be recorded during the interval. The command, "Stop!" at the end of the trial, and the release of the timer control were executed simultaneously. As a result there was, underlying the wave-form recording of respiration rate, a time-marker signal representing the duration of each trial. Consequently those breaths registered during the precise period of the trial could be readily distinguished and summed.

3. The subject was specifically instructed not to anticipate the finish of a performance, so that a partial (half or quarter) breath was frequently assessed at the end of a recording. The degree of precision justified in each case was dependent upon the rate of breathing.

The timing of MVV performance. All trials of MVV were carefully timed (see Figures III-iv and v). A Westclox electric wall clock with a twelve-inch face and a full-length sweep hand was marked at the edge with thin wedges of masking tape to indicate: (1) the commencement of a three-second countdown; (2) when the subject was to begin hyperventilation; and (3) the twelve-second mark, at which time he would be stopped. All four quadrants of the clock were prepared for alternative use.

The effecting of prescribed breathing rates. A Franz electric metronome (model LM-FB-4) was used by the technician to vigorously demonstrate MVV at a prescribed rate. The subject then practised passively for 5-10 seconds, until confident that he could remember the rate after the metronome was switched off. A trial of MVV was then performed.

Data Collected Prior to Testing Vital Capacity and MVV

When the subject entered the laboratory on Day #1 he stripped to the waist, shed his shoes, emptied his pant pockets, and had height, weight, and age recorded. After receiving instruction and a demonstration of the vital capacity maneuver, he performed it once or twice, depending on the completeness and regularity of the tracing for the first attempt. (On Day #2 and #3 all subjects again performed one satisfactory vital capacity maneuver).

The subject was then quizzed regarding any history of impairment to the respiratory system, such as asthma, emphysema, bronchitis, or pulmonary fibrosis. He was also asked if he were subject to any

current respiratory infection or congestion. The information was recorded, and none of the subjects were rejected at this time.

Information was obtained regarding smoking, as follows: (1) whether or not the subject smoked, or had smoked; (2) the approximate number of cigarettes he smoked per week; and (3) the number of years he had smoked.

The Three Experiments Designed to Investigate MVV

Each MVV experiment involved two groups of twelve subjects. In Experiment #1 and #2 each group underwent a different treatment condition. In Experiment #3 the twenty-four subjects were arranged in high and low vital capacity groups for purposes of comparison of MVVs. The placement occurred after all subjects had experienced the same treatment conditions.

Subjects in all three experiments performed three twelve-second trials of MVV on three alternate days during correspondingly appointed twenty-minute periods.

For treatment conditions requiring other than free-rate hyperventilation, the prescribed rate desired of the subject was different for each trial on any given test day. (The method of establishing the order of presentation of these rates attempted will be described in reference to individual experiments.)

Standardized instruction was provided in the performance of MVV (see Appendix B).

Experiment #1. The two treatment instructions used in Experiment #1 are as follows: (1) Group 1A subjects were told prior

to and during each trial to, "Breathe as deeply and as quickly as you can throughout the twelve-second trial!" (D&Q!") This, of course, corresponds closely to the recognized standard instruction. (2) Individuals in Group 1B were instructed to, "Get as much air into that (Douglas) bag as you can in twelve seconds!" (GMABC!").

Experiment #2. The twenty-four subjects assigned to Experiment #2 performed three free-rate trials on Day #1. They were then paired into treatment conditions by first ranking their mean MVV scores and assigning the subjects alternately to the two conditions. (The three trials, Session #1, served the function of a pre-test.) On Day #2 and #3, Group 2A continued with three trials of MVV at free rate of respiration, thereby acting as a control group. Group 2B endeavoured to reproduce metronomed rates of 112, 148 and 184 BPM. The order of rates at which trials were undertaken by subjects in Group 2B, Day #2 and #3, was determined by using four different blocks of six permutations. The instruction, "GMABC!" applied throughout Experiment #2 to subjects assigned to both treatment conditions.

Experiment #3. The twenty-four subjects attempted to reproduce rates of 76, 112 and 148 BPM in trials of MVV, performing one trial at each level on each of the three days. Similarly, as for Group 2B, the order of rates was assigned to subjects in blocks of six, so that the four blocks given Day #1 were all different. On Day #2 and #3, all orders of respiration rate were rotated one position to provide a total of twelve different blocks of rates. Subsequently, on the basis of their ranked mean vital capacities, the twenty-four test

subjects were divided into a high and a low vital capacity group. The MVV results were interpreted in this context.

Statistical Analysis of the Data

By the use of computer program G2011 at The University of Alberta, means, variances, standard deviations, sums of squares and cross products, and Pearson's product-moment correlation coefficients of body characteristics, minute volumes, breathing rates and other pertinent variables, were obtained.

A two-way analysis of variance for repeated measures (39:306) programmed for computer by P.S. Taylor at The University of Alberta, was used in connection with Experiment #1. The same analysis was contemplated for Experiments #2 and #3, but was discarded in both cases for reasons to be stated in Chapter IV.

The Newman-Keuls procedure (39:309) was used to achieve information with respect to mean differences of intersession minute volumes of MVV and associated breathing rates (two separate analyses of Experiment #1).

TABLE III:1

DESIGN SUMMARY OF THE THREE EXPERIMENTS INVOLVING REPEATED MEASURES OF MVV

Exp. and Group	Subjects	Instructions	Sessions 1 Trials 1 2 3	Sessions 2 Trials 1 2 3	Sessions 3 Trials 1 2 3
#1					
A	1 2 3 . 12	"D&Q!"	Free-rate MVV, all nine trials. Metronomed demonstration preceding first trial each session.		
B	1 2 3 . 12	"GMABC!"	As for Group 1A, apart from the different directive.		
#2					
A	1 2 3 . 12	"	Pre-test treatment condition as for Group 1B. Subjects then matched	Control condition (as for Group 1B)	
B	1 2 3 . 12	"	into Groups 2A and 2B on the basis of means of Trials 1-3 of MVV	Attempted rates of: 112 148 184 112 148 184 (Vigorous demonstration and passive practice to metronome prior to each trial)	
#3		<u>High VC</u>			
A	1 2 3 . 12	"	Trials #1-9 begun with demonstration and practice (as for Group 2B, Session #2 and #3). Subjects ungrouped for testing, then ranked in order of mean VC (three trials). Data analyzed according to high and low VC classification.		
		<u>Low VC</u>			
B	1 2 3 . 12	"	Permutated BPM rates attempted: 76 112 148	Order of rates attempted by each, rotated: 112 148 76	Attempted rates again rotated: 148 76 112

TABLE III:2

SUMMARY OF PROBLEMS INVESTIGATED, ASSOCIATED HYPOTHESES, AND METHODS OF ANALYSIS OF THE EXPERIMENTAL DATA

Problems Investigated	Associated Hypotheses	Methods of Analysis	Expt.
I. Effectiveness of the traditional test of MVV with respect to:			
A. Instruction	"GMABC!" is as effective as "D&Q!" in achieving optimal minute volumes	(1) Two-way AV for repeated measures of minute volumes (39:306)	#1
B. Respiration rate	A subject caused to breathe faster than at a freely elected rate more closely approaches optimal MVV	(1) Tabular and graphic representation re breathing rate;	#2;
		(2) "$A_{(1)}$", and a similar analysis of MVV breathing rates; and (3) Newman-Keuls tests for mean differences between (a) MVVs; and (b) breathing rates (39:309)	#1
C. Practice	There is an inter-session practice effect for the test of MVV	(1) "$A_{(1)}$" above; and (2) "$B_{(3a)}$" above.	#1
II. Subsidiary problems:			
D. Intuitive rate re optimal MVV	A subject does not intuitively choose a breathing rate that provides optimal MVV	Graphic representation and inference	#3
E. 100 BPM re optimal MVV	Mean optimal rate of MVV is in excess of 100 BPM	As for "$B_{(3)}$"; and graphic representation and inference.	#1; #3; and #1-3

TABLE III:2 (Continued)

	Problems Investigated	Associated Hypotheses	Methods of Analysis	Expt
F.	The validity of the largest minute volume of three trials as a measure of that parameter	The largest of three trial values of MVV is no more valid a measure of that parameter than is the mean	Comparison of mean volumes and correlations for best scores and means of three trials	Group 1B and 2A
G.	Optimal breathing rate and MVV in relation to VC	A greater VC is associated with a larger value of MVV at a faster breathing rate than is a lesser VC	Tabular and graphic representation and inference	#3
H.	Comparison of MVV and VC data with that in the literature; and correlation of age, height, weight and BSA with MVV and VC, and similar comparison		Means, S^2s, SDs and Rs (results of the present study and those reviewed) tabulated and compared	Group 1B and 2A; #1-3 combined
I.	Distinction between smokers and nonsmokers on the basis of MVV and VC scores	Nonsmokers are superior to smokers in tests of MVV and VC	MVV results discussed (analysis not defensible on basis of data); VC: one-tailed t-test ($\alpha \doteq 0.05$)	#1-3 combined (for both)

CHAPTER IV

RESULTS AND DISCUSSION*

I. The Hypothesis That the Directive "D&Q!" Was No More Effective Than That of "GMABC!" Was Supported by Investigation.

The results of Experiment #1, in which an attempt was made to distinguish between the effects of directives "D&Q!" and "GMABC!", are contained in Table IV:1. There was no appreciable disparity between group means for any of the nine trials. Departures from homogeneity of variance were found to be nonsignificant ($P < 0.05$). For the test used, see Ferguson (16:140).

A two-way analysis of variance for repeated measures (39:306) was performed (see summary, Table IV:2). Mean MVVs for the two groups given the separate directives, were not significantly different. Both age and the physical characteristics that most affect the level of MVV attained were found closely comparable in treatment Groups 1A and B, as indicated in Table IV:3. Therefore these variables appeared to have no bearing upon the results.

II. The Hypothesis That a Subject Caused to Breathe Faster More Closely Approaches Optimal MVV, Was Supported by Investigation.

A. Experiment #2 Ineffective

Experiment #2 was undertaken to investigate the hypothesis that the optimal value of MVV is more closely approached when the subject is

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*The nature, order and methods of analysis of the following problems investigated are summarized in Table III:2

TABLE IV:1

MVV MEANS, VARIANCES AND STANDARD DEVIATIONS, EXPERIMENT #1

Session	1			2			3		
Trial	1	2	3	1	2	3	1	2	3
Group 1A ("D&Q!")									
$\overline{X}$ (LPM)	193.38	197.48	197.77	207.67	202.10	204.26	206.66	203.47	197.65
s^2	286.78	319.49	439.16	421.21	400.41	315.97	486.43	510.32	605.76
s	16.93	17.87	20.96	20.52	20.01	17.78	22.06	22.59	24.61
Group 1B ("GMABC!")									
$\overline{X}$ (LPM)	193.58	199.98	202.67	208.71	207.70	207.16	210.32	209.68	208.34
s^2	646.77	479.30	633.77	605.49	643.64	524.53	677.29	616.61	669.27
s	25.43	21.89	25.17	24.61	25.37	22.90	26.02	24.83	25.87

TABLE IV:2

SUMMARY OF TWO-WAY ANALYSIS OF VARIANCE FOR THE INVESTIGATION OF INSTRUCTIONAL AND SESSIONAL MEAN DIFFERENCES OF MVV, EXPERIMENT #1

Source of Variation	SS	df	MS	F
Between subjects				
Instructions "D&Q!" and "GMABC!"	315.00	1	315.00	.26
Error	26,286.50	22	1,194.84	
Within subjects				
Mean MVVs for Sessions #1,2 and 3	1,204.91	2	602.45	5.36*
Instructions X Sessions	65.56	2	32.78	.29
Error	4,944.50	44	112.38	

* $F_{.95}(2,44) = 3.21$: discussed on page 53.

TABLE IV:3

AGE, HEIGHT, WEIGHT AND BSA STATISTICS, GROUPS 1A AND B

	Age	Height (Cm)	Weight (Kg)	BSA (M^2)
Group 1A ("D&Q!")				
$\bar{X}$	20.06	175.16	70.32	1.85
s^2	1.70	42.00	44.74	0.01
s	1.30	6.48	6.69	0.10
Group 1B ("GMABC!")				
$\bar{X}$	20.45	176.01	69.02	1.84
s^2	1.68	16.19	43.13	0.01
s	1.30	4.02	6.57	0.09

caused to breathe faster. The data for Sessions #2 and #3 was to have been processed by means of a two-way analysis of variance as used for Experiment #1. In the event of significant mean differences, Newman-Keuls tests (39:309) were intended for their investigation.

In reference to Figure IV:1 (lower diagram) a trend of increased breathing rates was apparent for Group 2A (unshaded circles) in the course of three test sessions. This trend was so pronounced that there was little to distinguish between the second and third sessional mean breathing rates for both treatment conditions intended for analysis.

Free rates of breathing selected by the control group (see Table IV:5) were unexpectedly fast in all three experiments; the grand total of 360 free-rate trials undertaken were performed at mean rate 137 BPM. As there was little reference in the literature to free unbiased rates of MVV for unobstructed subjects, the breathing rates achieved should have seemed less remarkable.

The possibility that the instructional difference "GMABC!" rather than "D&Q!" may have been responsible for the seemingly elevated rates of breathing was discounted on the basis of statistical evidence which appears in the next analysis. Whatever the explanation, the experimental design was rendered ineffective by the faster than expected breathing rates.

To conclude the discussion of Experiment #2, the impression gained from Tables IV:4 and 5, and Figure IV:1, was that there may be substance to the hypothesis under investigation. The inquiry was redirected to a statistical analysis of MVVs and breathing rates, Experiment #1.

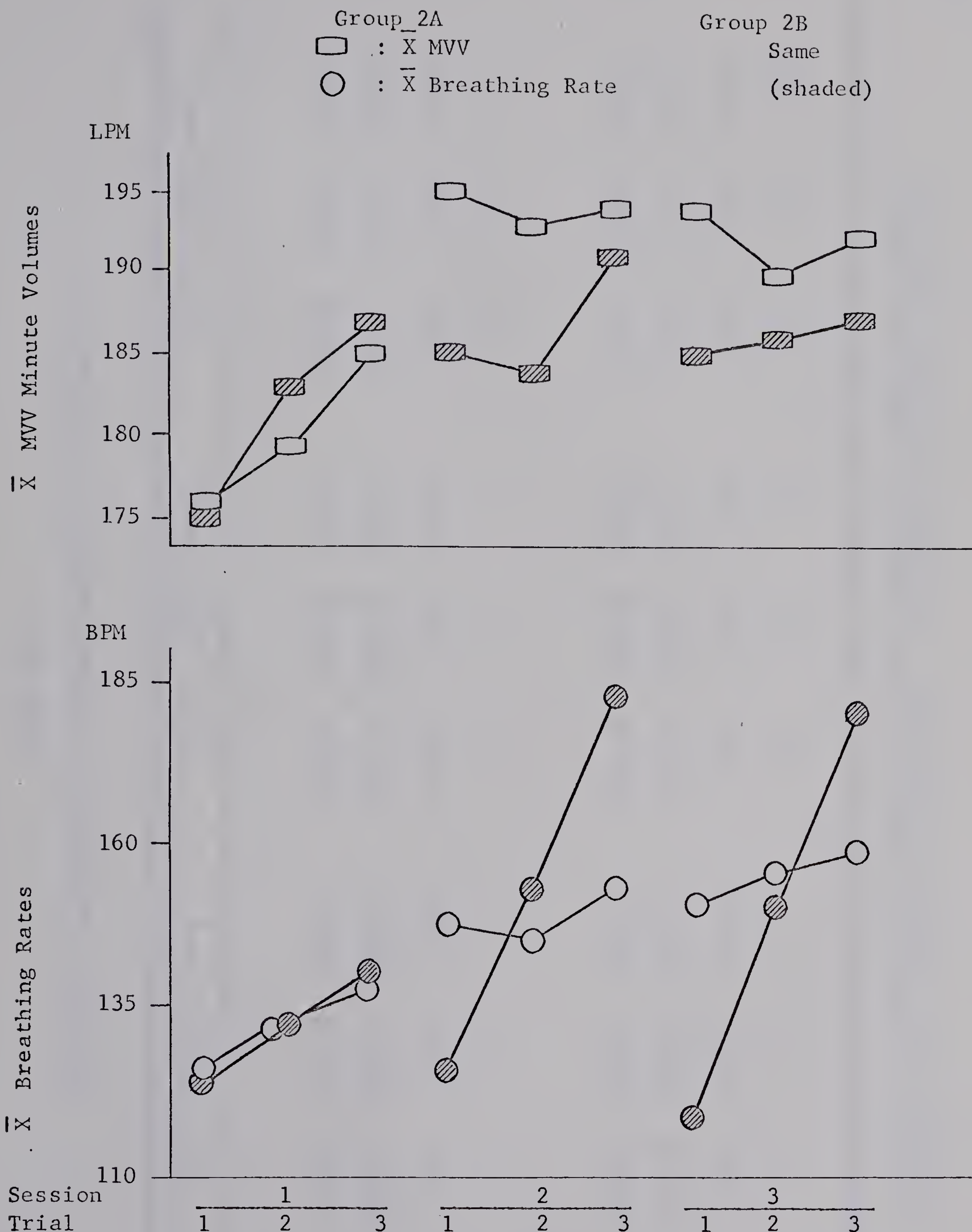

FIGURE IV:1 COMPARISON OF MEAN MVVs AND BREATHING RATES, EXPERIMENT #2 (Group 2B, Sessions #2 and #3: means for attempted breathing rates 112, 148 and 185 BPM, arranged in order)

TABLE IV:4

MVV MEANS, VARIANCES AND STANDARD DEVIATIONS, EXPERIMENT #2

Session	1			2			3		
Trial	1	2	3	1	2	3	1	2	3
Group 2A									
$\overline{X}$ (LPM)	175.82	179.46	184.71	195.68	192.98	194.35	193.66	189.95	191.52
s^2	620.27	698.97	1284.55	834.39	1092.75	610.32	824.63	947.20	817.23
S	24.91	26.44	35.84	28.89	33.06	24.70	28.72	30.78	28.59
Rate	F	F	F	F	F	F	F	F	F
Group 2B									
$\overline{X}$ (LPM)	174.77	182.51	186.73	185.30	184.16	190.53	185.10	186.02	187.21
s^2	572.75	610.59	865.12	748.65	792.66	824.78	438.26	553.19	590.10
S	23.93	24.71	29.41	27.36	28.15	28.72	20.93	23.52	24.29
Rate (BPM)	F	F	F	112	148	184	112	148	184

Statistics for Group 2B, Sessions #2 and #3, arranged in progressive order of breathing rates attempted, as indicated. "F" signifies free-rate respiration.

TABLE IV:5

MEANS, VARIANCES AND STANDARD DEVIATIONS OF MVV BREATHING RATES, EXPERIMENT #2

Session	1			2			3		
Trial	1	2	3	1	2	3	1	2	3
Group 2A									
$\overline{X}$ (BPM)	124.58	133.00	138.42	146.75	144.08	153.00	149.58	155.83	160.92
S^2	1526.81	1022.00	1064.99	608.20	600.08	1149.09	1018.45	549.79	886.81
S	39.07	31.97	32.63	24.66	24.50	33.90	31.91	23.45	29.78
Rate	F	F	F	F	F	F	F	F	F
Group 2B									
$\overline{X}$ (BPM)	122.00	133.58	140.08	126.08	152.42	182.25	117.33	148.67	179.58
S^2	347.45	691.72	1193.17	329.36	128.27	191.84	66.42	218.61	139.36
S	18.64	26.30	34.54	18.15	11.33	13.85	8.15	14.79	11.80
Rate (BPM)	F	F	F	112	148	184	112	148	184

Statistics for Group 2B, Sessions #2 and #3, arranged in progressive order of breathing rates attempted, as indicated. "F" signifies free-rate respiration.

B. <u>The Analysis of Breathing Rates and MVVs, Experiment #1</u>

The MVV breathing rate statistics for both instructional groups, Experiment #1 are represented in Table IV:6. The extent of variability of these breathing rates was more apparent than that for the associated minute volumes of the same experiment. However, only the respective variances for Trial #1, Session #3, were found not to be homogeneous (P = 0.01). For the test used, see Ferguson (16:140).

Aware that one of the assumptions of the analysis of variance was homoscedasticity, and that Ferguson (16) considered moderate departures did not seriously affect the validity of inferences drawn, a two-way analysis of variance for repeated measures (39:306) was performed (summarized in Table IV:7). Two levels of instruction were "D&Q!" and "GMABC!", and three levels of breathing rate were the mean rates for the three test sessions.

From the analysis of variance the effects due to the different instructions were not distinguishable in respect to breathing rates observed. However, an intersession difference in mean breathing rate appeared significant ($P < 0.05$). This result, in combination with a significant intersession difference between mean MVVs ($P < 0.05$: see Table IV:2), led to an investigation in both cases of the differences between all pairs of means. The Newman-Keuls method (39:309) was used, and the results are as follows:

1. For intersession differences in mean MVVs, Experiment #1, $H_1 : b_2 > b_1; b_3 > b_1$ ($\alpha = 0.05$).

2. For intersession differences in mean MVV breathing rates, Experiment #1, $H_1 : b_2 > b_1; b_3 > b_1$ ($\alpha = 0.01$).

TABLE IV:6

MEANS, VARIANCES AND STANDARD DEVIATIONS FOR MVV BREATHING RATES, EXPERIMENT #1*

Session	1			2			3		
Trial	1	2	3	1	2	3	1	2	3
Group 1A ("D&Q!") (N = 12)									
$\overline{X}$ (BPM)	105.8	114.9	117.9	132.6	132.5	136.8	141.2	136.8	144.3
s^2	248.8	370.6	507.2	842.1	978.3	794.7	1029.8	683.1	1154.0
s	15.8	19.3	22.5	29.0	31.3	28.2	32.1	26.1	34.0
Group 1B ("GMABC!") (N = 12)									
$\overline{X}$ (BPM)	125.7	128.9	133.3	137.2	143.4	150.9	134.9	141.9	145.7
s^2	911.7	636.4	737.5	660.7	879.7	728.8	133.0	266.6	430.1
s	30.2	25.2	27.2	25.7	29.7	27.0	11.5	16.3	20.7

* Free-rate respiration for all trials, Experiment #1.

TABLE IV:7

SUMMARY OF TWO-WAY ANALYSIS OF VARIANCE FOR THE INVESTIGATION OF INSTRUCTIONAL AND SESSIONAL MEAN DIFFERENCES OF MVV BREATHING RATES, EXPERIMENT #1

Source of Variation	SS	df	MS	F
Between Subjects				
Instructions "D&Q!" and "GMABC!"	1395.69	1	1395.69	.94
Error	32586.30	22	1481.20	
Within Subjects				
Mean breathing rates Sessions #1, 2 and 3	5755.03	2	2877.52	19.75*
Instructions X Sessions	808.34	2	404.17	2.77
Error	6409.94	44	145.68	

* $F_{.95}(2,44) = 3.21$

The mean sessional values of MVV and breathing rate are recorded in Figure IV:2.

What then are the implications of the results in respect to the hypothesis that a subject caused to breathe faster than at a freely elected rate more closely approaches optimal MVV?

Although not by design, as was the intention in Experiment #2, subjects were caused to breathe significantly faster ($P < 0.05$) on a second and third test day than they chose to do during the initial session. The reason for this increased rate would appear to be either added motivation and/or the practice effect of performing the test. Correspondingly, MVVs were significantly larger ($P < 0.01$), Sessions

#2 and #3. On these occasions mean values were similar at 206.0 LPM (SD: 23.7) and 206.3 LPM (SD: 21.4), as were free breathing rates. Therefore it would appear justifiable to infer that these analyses supported the hypothesis under investigation.

It could be argued that practice and motivation are significant in the achievement of larger MVVs, and that increased breathing rate is not. In Experiment #3 (see Figure IV:3) the effect of practice and motivation could be inferred because MVVs were larger for successive trials at somewhat controlled rates (practised to metronome). However, the effect of rate was clearly observed from a trend of increased minute volumes which accompanied successive levels of breathing rate attempted each test session. (The effect of ordered presentation was eliminated.)

III. The Hypothesis That an Intersession Practice Effect Is Intrinsic to the Test of MVV, Was Supported by Investigation.

The hypothesis that a practice effect applies when the test of MVV is repeated over a series of test sessions, was investigated.

From an analysis of MVV minute volumes, Experiment #1, referred to in Section B of the previous investigation, mean MVVs were calculated as being significantly larger, Sessions #2 and #3, than they were, Session #1 ($P < 0.05$). This result may be inferred as being valid support of the hypothesis under investigation. However, the problem is confounded by the additional effect of significantly increased breathing rates, Sessions #2 and #3 (again, see Section B of the previous investigation).

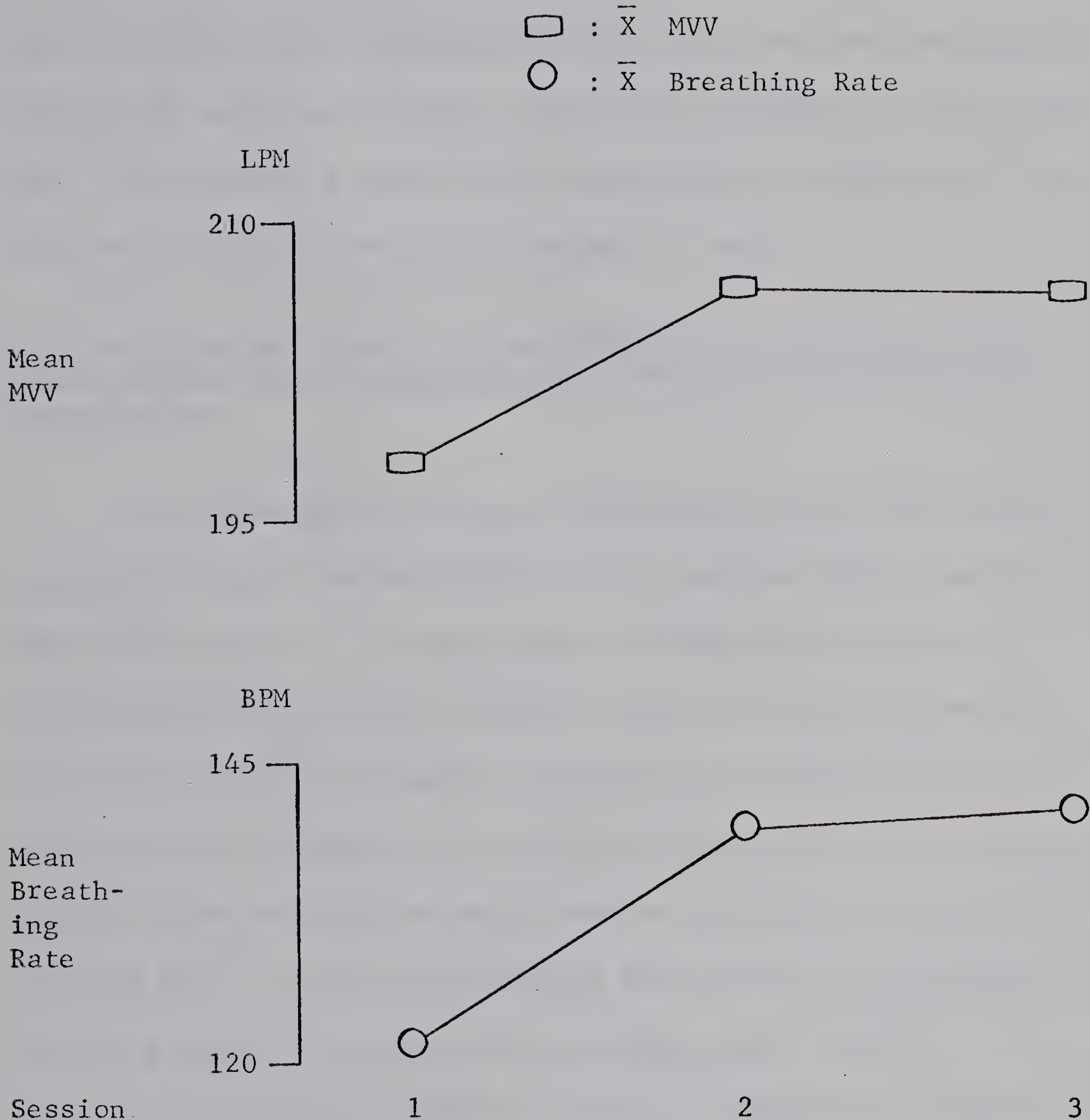

FIGURE IV:2 MEAN SESSIONAL MVVs (upper diagram) AND BREATHING RATES (lower diagram) FOR COMBINED GROUPS A AND B, EXPERIMENT #1

Session #2 and #3 means significantly greater than Session #1 mean ($P < 0.01$: MVVs; and $P < 0.05$: breathing rates)

Inferred support of the hypothesis investigated is in agreement with the result achieved by Friend (17), who administered five three-trial sessions of MVV to five medical students on consecutive days, and observed a significant mean increase of MVV, Day #2, as compared to Day #1 ($P < 0.001$, using a t-test).

IV. The Hypothesis That a Subject Does Not Intuitively Choose a Breathing Rate That Provides Optimal MVV, Was Not Supported by Investigation.

An investigation of the relationship between intuitively chosen breathing rate and optimal MVV presupposes that rate has a significant effect. In this respect, although the design of Experiment #3 is such that the data cannot be used to provide a statistical decision, graphic representation (Figure IV:3) is indicative that breathing rates and MVV minute volumes are intimately related. The mean MVV for each level of breathing rate attempted, Sessions #1-3, and the corresponding grand means are represented, as well as a record of mean actual breathing rates adopted.

The hypothesis under scrutiny was formulated on the basis of reviewed literature which made scant reference to optimal breathing rates for unobstructed subjects. Indications were that intuitive rates would be significantly slower than the free rates demonstrated in this study. As it occurred, for the grand total of 360 trials performed at free rate by Groups 1A, 1B, 2A and 2B (Session #1), the mean MVV was 196.7 LPM, and the breathing rate, 137 BPM. In reference to Figure IV:3, it can be observed that these values are similar to those for seventy-two trials attempted at 148 BPM by Groups 3A and B.

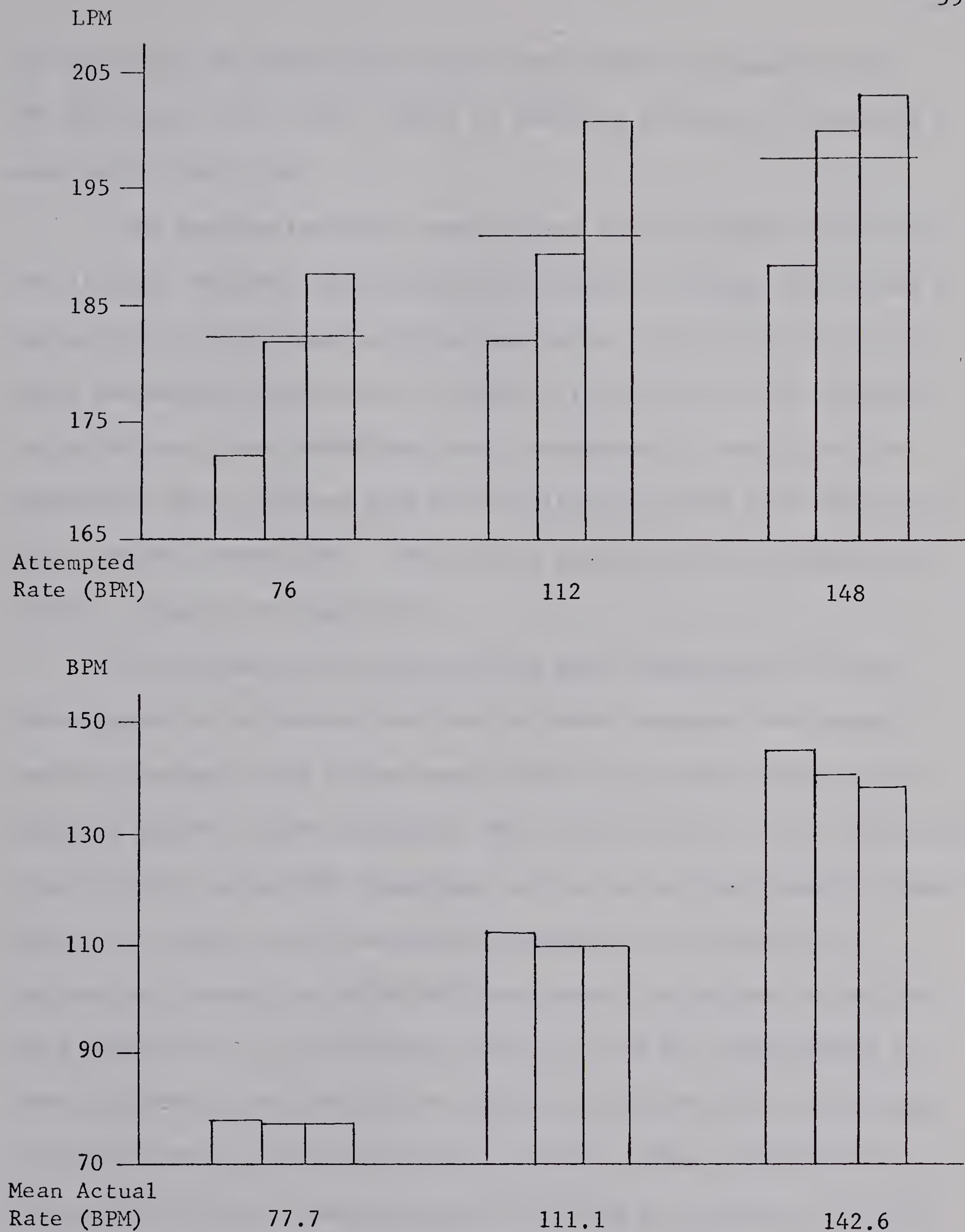

FIGURE IV:3 MEAN MVVs AT ATTEMPTED BREATHING RATES 76, 112 AND 148 BPM (upper diagram), AND CORRESPONDING MEAN BREATHING RATES (lower diagram), GROUPS 3A AND B COMBINED

The levels indicated are mean MVVs for each breathing rate attempted

By comparison the twenty-four trials undertaken at attempted rate 184 BPM (mean actual rate: 180.9) by subjects in Group 2B, provided a mean MVV of 188.9 LPM.

The implications that can be drawn from the above information are limited, however, particularly as subjects in Groups 2B, 3A and B had only restricted opportunity to perform at the levels of rate at which comparisons were made. In effect, test data was not obtained at sufficiently fast breathing rates to adequately investigate the hypothesis that a subject does not intuitively choose a breathing rate that provides optimal MVV. The limited inferences that could be made tended to negate the hypothesis.

An observation that arises from this investigation is that there appear to be indications from the data discussed that experimental procedures used in the test of MVV to date have biased and restricted optimal values attained. More specifically, if the technician conceives the optimal MVV breathing rate as being significantly slower than it is, then he will undoubtedly demonstrate the maneuver accordingly (usually at 60-80 BPM) and exhort the subject to perform at a similar rate. In contrast, prior to Trial #1, each session of free-rate MVV in this study, the technician demonstrated to metronome set at 100 BPM but drew no attention to rate. What would have been the effect of such a demonstration at 135 BPM on the mean of the 360 free-rate trials performed in this study?

V. The Hypothesis That Mean Optimal MVV Breathing Rate Is in Excess of 100 BPM, Was Supported by Investigation.

Conclusions from experimentation (3,4,34) that the optimal breathing rate for the test of MVV lies in the vicinity of 100 BPM, were made from assessments of data that did not provide adequate knowledge of performance at higher rates.

From an analysis of Experiment #1 of this thesis it was observed that the twenty-four subjects achieved significantly larger minute volumes at approximately 140 BPM than at 120 BPM, Session #1. From this result 100 BPM could not be inferred as being optimal.

Recorded in Figure IV:3 are mean MVVs at attempted breathing rates 76, 112, and 148 BPM. Largest minute volumes were obtained at an actual mean rate of 142.6 BPM, whereas 111.1 BPM, the actual mean rate for attempted 112 BPM, might have been expected to provide largest values if 100 BPM were optimal.

Perhaps the best indication of just how optimal is a breathing rate of 100 BPM, can be observed from Figure IV:4. In the course of a grand total of 120 test sessions involving forty-eight subjects, the largest MVV for a given subject undergoing a given test session was on twenty-seven occasions within a range of 100 ± 15 BPM. In comparison, sixty-three such scores for a session were attained at rates in excess of 115 BPM. None of the performances were observed as rates slower than eighty-five BPM.

It was concluded that the analysis of data undertaken inferred support of the hypothesis that the mean optimal breathing rate for the test of MVV is in excess of 100 BPM.

VI. The Hypothesis That the "Best" MVV Is No More Valid an Indication of That Parameter Than Is the Mean of Three Trials, Was Supported by Investigation.

Because one measure is confounded in the other there appeared to be no way to test statistically the hypothesis that the largest MVV achieved during a test session provides any more valid an indication of that parameter than does the mean of the three trials. However, an assessment of correlation coefficients with respect to largest minute volumes per test session and means for all three trials per test session, seemed valid and applicable.

An important aspect of validity is reliability, and it was observed from Table IV:8 that for combined Groups 1B and 2A the inter-session reliability of the "best" MVVs was practically identical to that for the mean of the three trials.

Correlations of age, body characteristics, and mean vital capacity, with largest MVVs per session and means for all three trials, are represented in Table IV:9. The correlation coefficients for both measures of MVV are similar and consistent, as reference to the table will indicate. (The small age range of the subjects tested is apparently the reason why the age correlations approached zero. The minute volumes achieved by combined Groups 1B and 2A, Session #2, were 207.2 LPM (SD: 27.2) and 201.1 LPM (SD: 26.3) respectively. Even if there were a method available to test the difference between these means, it appears unlikely that the difference would be statistically significant.

The inferences that could be drawn from this investigation

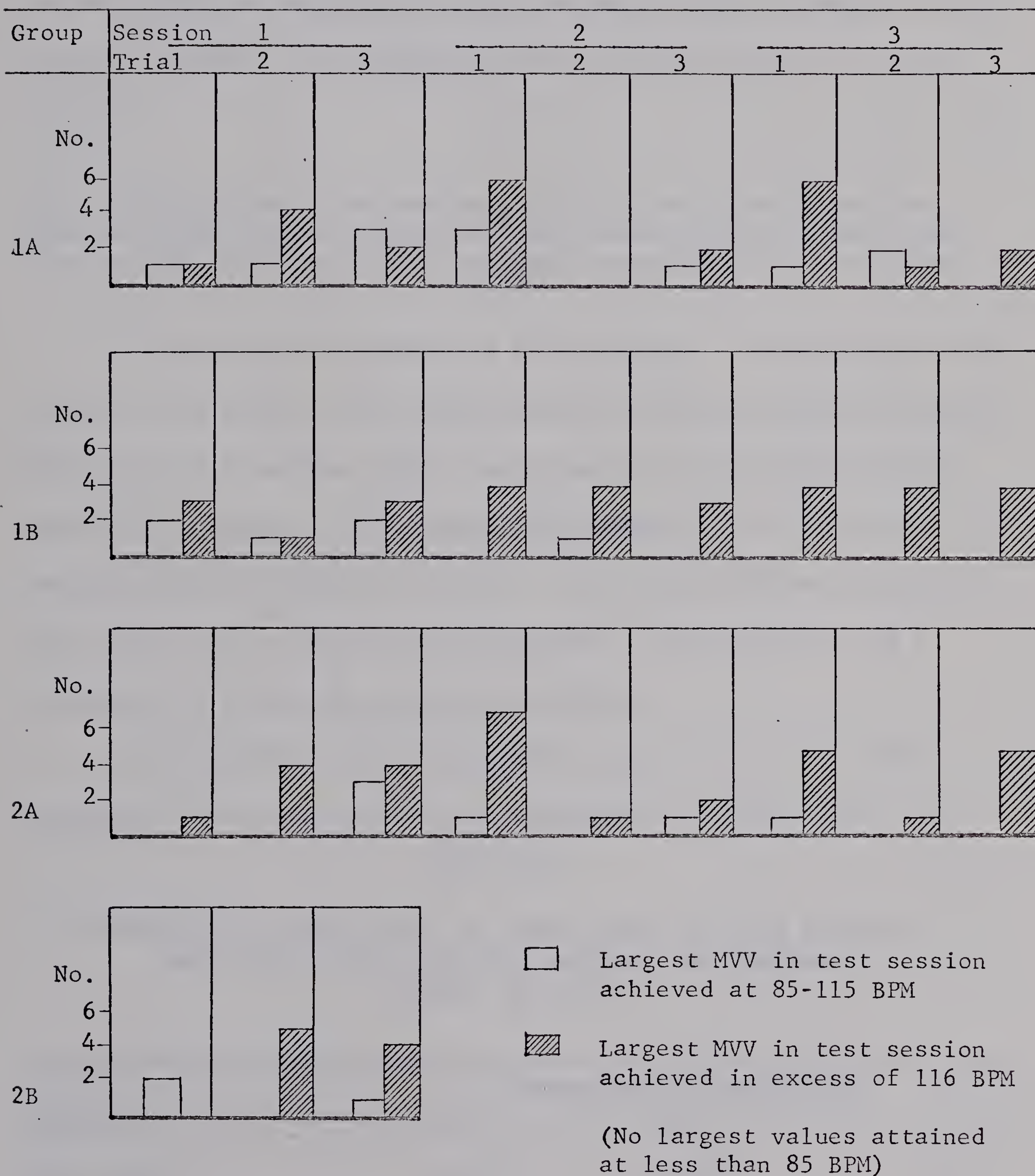

FIGURE IV:4 OCCASIONS PER SESSION SUBJECTS PERFORMING FREE-RATE MVV ACHIEVED LARGEST VALUES AT BREATHING RATES 85-115 BPM OR FASTER

supported the hypothesis that the "best" MVV during a test session is no more valid an indication of that parameter than the mean of three trials. However, the complexity of the problem limited its investigation.

VII. The Hypothesis That Subjects with Greater Vital Capacities Achieve Largest Values of MVV at Faster Breathing Rates Than Those with Smaller Vital Capacities, Was Not Supported by Investigation.

Experiment #3 was devised to investigate the hypothesis that subjects with greater vital capacities more closely approach optimal MVV at faster breathing rates than do subjects with smaller vital capacities. However, the experimental design did not lend itself to comprehensive statistical analysis. As a result limited inferences were drawn from an appraisal of graphical representations and a comparison of means and standard deviations.

The mean MVVs of subjects with larger and smaller vital capacities (Groups 3A and B) are represented in Figure IV:5.

TABLE IV:8

INTERSESSION CORRELATIONS OF "BEST" MVVs PER TEST SESSION, AND OF MEAN MVVs PER TEST SESSION, FOR COMBINED GROUPS 1B AND 2A

	Correlation Coefficients		
Sessions	1:2	1:3	[illegible]:3
"Best" MVVs	0.90	0.90	0.91
Mean MVVs	0.89	0.88	0.88

TABLE IV:9

CORRELATION OF SELECTED PHYSICAL CHARACTERISTICS WITH "BEST" MVVs PER TEST SESSION, AND WITH MEAN MVVs PER TEST SESSION, FOR COMBINED GROUPS 1B AND 2A

	"Best" MVVs			Mean MVVs		
Session	1	2	3	1	2	3
Coefficient of Correlation for						
Age	0.07	-0.03	0.02	0.02	0.01	0.02
Height	0.50	0.43	0.36	0.45	0.47	0.38
Weight	0.03	-0.01	0.09	-0.04	0.02	0.09
BSA	0.13	0.09	0.16	0.07	0.13	0.17
$\bar{X}$ VC	0.62	0.53	0.51	0.61	0.54	0.49

TABLE IV:10

BREATHING RATE STATISTICS FOR "BEST" MVVs PER TEST SESSION, IN RESPECT TO LARGER AND SMALLER VC GROUPS, 3A AND B

		Breathing Rates For "Best" MVVs		
Session		1	2	3
Larger Vital Capacity Group, 3A	$\bar{X}$	120.4	125.8	126.8
	s^2	703.0	893.3	336.8
	s	26.5	29.9	18.4
Smaller Vital Capacity Group, 3B	$\bar{X}$	127.8	123.9	121.5
	s^2	433.6	581.0	404.1
	s	20.8	24.1	20.1

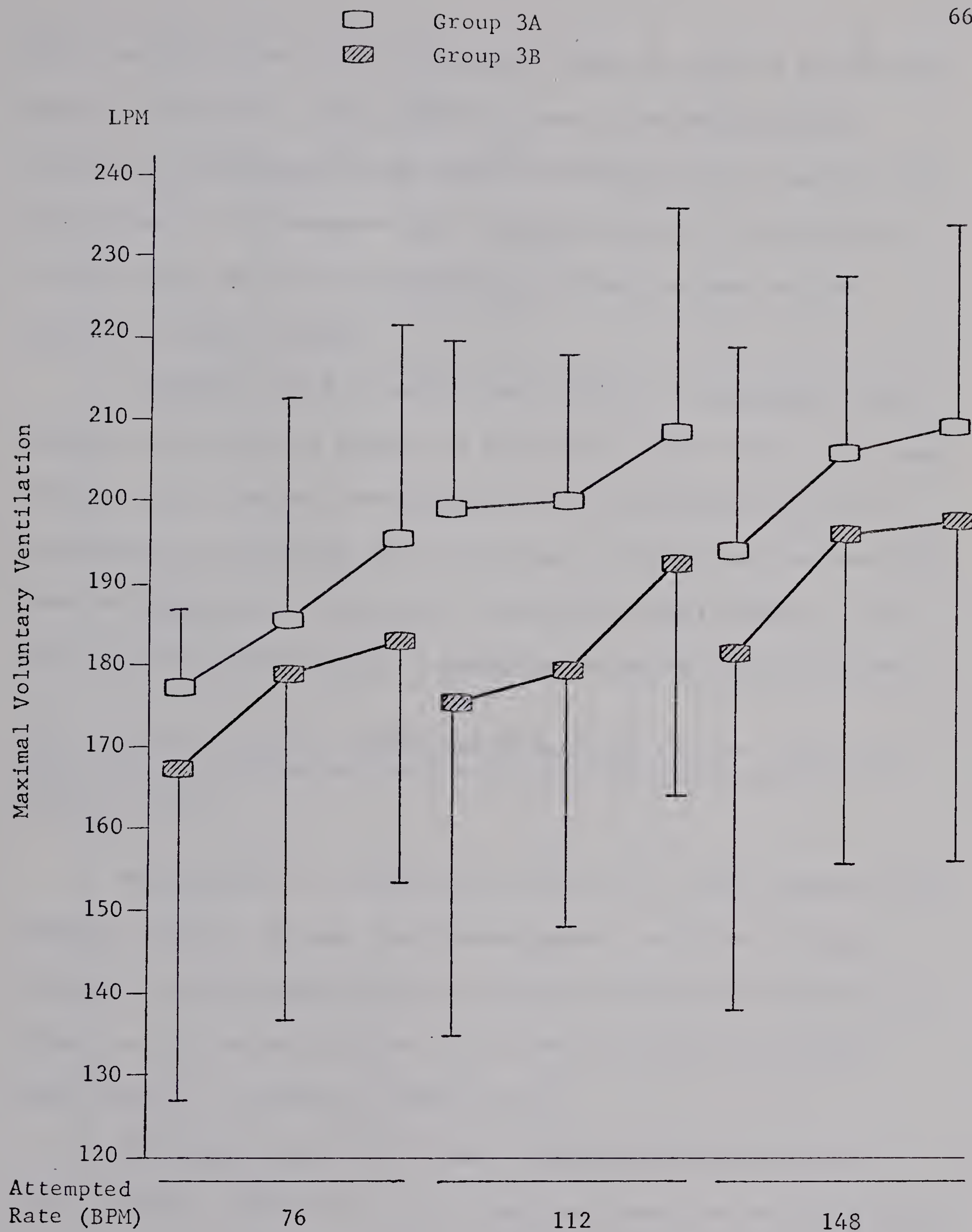

FIGURE IV:5 MEANS AND STANDARD DEVIATIONS FOR MVVs OF GROUPS 3A AND B (LARGER AND SMALLER VITAL CAPACITY DICHOTOMIES)

Means were obtained by ordering the data to that of attempted breathing rates 76, 112 and 148 BPM

The three trials for each of attempted rates 76, 112 and 148 BPM are graphed in sequence, and a distinct trend of increasing minute volumes in accompaniment with faster breathing rates is apparent for both groups. The responses were so similar that it could only be inferred that the evidence indicated as being contrary to the hypothesis under scrutiny.

Breathing rates at which "best" MVVs per test session were obtained for Groups 3A and B, are recorded in Table IV:10. The same inference was drawn as from Figure IV:5. The breathing rates recorded for the two groups were so similar, it could only be concluded that the larger and smaller vital capacity groups responded in the same way to increased rates of breathing during performance of MVV.

VIII. Sample Estimates of MVV and VC Recorded in This Study, Their Correlation with Physical Characteristics, and Comparison with Reported Values.

For purposes of comparison, Tables II:1-3 which summarize the research data for the age level investigated, reappear as Tables IV:11-13 with the addition of the information obtained in this study. (These statistics are set down in the order of mean age for each group, which is recorded in Table IV:12.)

The largest mean MVV of 201.0 LPM (SD: 26.3) recorded in Table IV:11 was obtained in this study, and there are several possible explanations for its magnitude.

1. The Douglas bag technique for testing MVV is acknowledged as providing larger minute volumes than those achieved by spirometer. Stuart and Collings (38) and Needham _et al_. (33) used it; others

TABLE IV:11

MEANS AND STANDARD DEVIATIONS OF MVV AND VC IN SELECTED MALE STUDIES AND IN THE PRESENT STUDY

Study	N	MVV(LPM)		VC(L)		Nature of Sample
		Mean	SD	Mean	SD	
Needham _et_ _al_. (33)	78	103.0	32.0	3.45	0.98	Youths, 11-19 years
	16	136.5		4.56		Youths, 18 and 19 years (in above)
Present study	24	201.1	26.3			Undergraduates; mean age, 20.2 years (Groups 1B and 2A)
Present study	72			5.46	0.69	Undergraduates; mean age, 20.4 years (all groups)
Gray _et_ _al_. (21)	89	167.8	22.1			Aviation cadets
Stuart and Collings (38)	20	192.0	32.0	5.29	0.75	Sedentary medical students
	20	197.0	32.0	5.69	0.67	Conditioned athletes, matched by A, H, and W to the above group
Boren _et_ _al_. (8)	115	184.0	29.0	4.82*	0.65	Unobstructed patients and staff
Baldwin et al. (1)	17	126.0	28.6	4.01	0.62	Unobstructed patients, 16-34 years

* Subjects tested in the semi-recumbent position.

TABLE IV:12

MEAN BODY CHARACTERISTICS OF SUBJECTS IN SELECTED MALE STUDIES OF MVV AND VC AND IN THE PRESENT STUDY

Study	N	Age (Yrs) Mean	Age (Yrs) SD	Height (Cm) Mean	Height (Cm) SD	Weight (Kg) Mean	Weight (Kg) SD	BSA (M^2) Mean	BSA (M^2) SD
Needham <u>et</u> <u>al</u>. (33)	78	15.3	2.60	160.5	14.48	50.98	12.84	1.51	0.27
	16*	18,19		176.3		66.23		1.82	
Present study (Groups 1B, 2A)	24	20.2	1.00	176.1	5.62	70.17	9.53	1.86	0.13
Present study (all groups)	72	20.4	1.42	176.3	5.99	71.61	8.83	1.88	0.13
Gray <u>et</u> <u>al</u>. (21)	89	20.9	2.54	176.9	6.53	72.80	6.58	1.88	0.11
Stuart and Collings (38)	20**	22.7	2.34	181.4	6.60	76.20	8.16	1.97	0.14
	20	20.6	1.30	181.6	6.35	76.61	10.93	1.97	0.13
Boren <u>et</u> <u>al</u>. (8)	115	25.1	2.70	176.0	7.62	75.75	12.70	1.91	0.17
Baldwin <u>et</u> <u>al</u>. (1)	18	25.5	6.00	173.8	8.60	66.00	8.30	1.77	0.14

* Included in the above.
** Sedentary students (below: conditioned athletes).

TABLE IV:13

CORRELATIONS OF MVV AND VC WITH PHYSICAL CHARCTERISTICS, IN SELECTED MALE STUDIES AND IN THE PRESENT STUDY

Study	Needham *et al.* (33)	Present Study	Stuart and Collings (38)	Stuart and Collings (38)	Baldwin *et al.* (1)
No. of Subjects	78	24/72	20	20	52
Sample	Youths, 11-19 Yrs	Varsity Students	Sedentary Students	Athletes	Unobstructed Patients
Maximal Voluntary Ventilation with		(N=24)			
Age	0.83				-0.63
Height	0.84	0.47	0.46	0.35	0.41
Weight	0.89	0.02	0.43	0.45	0.27
Surface Area	0.90	0.13	0.46	0.48	0.36
Vital Capacity with		(N=72)			
Age	0.86				-0.43
Height	0.89	0.67	0.65	0.46	0.49
Weight	0.91	0.33	0.68	0.44	0.23
Surface Area	0.93	0.49	0.73	0.49	0.44

whose studies are listed did not.

2. Twelve-second trials were undertaken in the studies by Stuart and Collings (38) and Boren *et al*. (8). This procedure appears to elevate scores. Both of the above measures were adopted in this study.

3. The mean breathing rate was considerably faster than at least that for the Stuart and Collings experiment. These authors reported a mean breathing rate of 108 BPM (SD: 21.5); the others did not record rates.

4. It must also be observed that the MVV tabulated for the present study was the mean of the three trials, Session #2. Stuart and Collings reported the mean of best MVVs for one session only. In comparison to this result reported by Stuart and Collings, the corresponding mean MVV for the present study was 198.2 LPM (SD: 28.6) at a mean breathing rate of 130.5 BPM (SD: 23.6).

Correlation coefficients for mean MVV, Session #2 of the present study (see Table IV:13) were nonsignificant in respect to weight and body surface area (0.02; 0.13), correlation with height (0.47: $0.05 > P > 0.02$) accorded with other tabled values.

The mean vital capacity for the present study was 5.46 litres (SD: 0.69), and only the athletes tested by Stuart and Collings (38) provided larger mean volumes. This extent of vital capacity was perhaps a significant factor in the achievement of a notably large MVV.

From the summary of body characteristics (see Table IV:12) it appears that the experimental groups were substantially the same, so that these variables cannot be inferred as being responsible for

observed differences. Correlation coefficients for height, weight and body surface area with vital capacity were all significant in the present study. (Weight was such at $P < 0.01$, the others at $P < 0.001$.) The correlation between vital capacity and the mean MVV of three trials for combined Groups 1B and 2A, Session #1, was 0.54.

IX. The Hypothesis That Nonsmokers Demonstrate Superior Performance in Tests of VC and MVV Than Do Smokers, Was Not Supported by Investigation.

The experimental design of this thesis was not established with any intention of investigating the hypothesis that nonsmokers achieve superior scores of VC and MVV in comparison to smokers. Consequently only a brief account of the results is justified. Only fifteen of the seventy-two test subjects were smokers, and they were distributed throughout the MVV test conditions. Therefore a valid comparison between the pulmonary function of smokers and nonsmokers was not possible on the basis of a test of MVV. The vital capacities of the two groups were very similar. Respective mean values were 5.43 litres (SD: 0.80) and 5.47 litres (SD: 0.67).

The mean age of the subjects tested was 20.4 years (SD: 1.4), so that histories of smoking were necessarily short. By comparison, Hensler and Giron (24) observed nonsmokers to achieve significantly larger MVVs and VCs than smokers, but smoking histories in the test sample ranged 15-25 years. Therefore, even if this thesis had been specifically designed to investigate smoker-nonsmoker differentiation in pulmonary function, it is doubtful that significant differences would have been obtained for the age level selected.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The main purpose of this study was to investigate significant variables associated with the test of maximal voluntary ventilation (MVV), and subsequently to determine the means of improving the test should this need be indicated. Principally investigated were, the effects of the directive, respiration rate, and practice.

A random sample of seventy-two second year undergraduate University of Alberta males participated in three MVV experiments, twelve subjects being assigned to each of two treatment conditions in each investigation. All subjects performed three trials per session on three alternate days. The treatment variables were the prescribed directive and breathing rate.

MVV minute volumes and breathing rates were recorded for all trials. The data, and that for vital capacity, were computer processed to obtain means, variances, standard deviations and correlation coefficients. The hypotheses formulated were tested where applicable by the use of a two-way analysis of variance for repeated measures, and the Newman-Keuls procedure for investigating mean differences.

In addition to an investigation of the test of MVV, the mean MVV obtained for the normal treatment condition was compared to that for groups of similar mean age reported in the literature. The same groups were compared in respect to the physical characteristics

associated with the performance of MVV, and for correlations between these variables. Similar comparisons were made for vital capacity. The seventy-two subjects who performed MVV also took part in the vital capacity maneuver.

A summary of the estimates of MVV and vital capacity, and significant correlations obtained in the present study is as follows:

1. Mean MVV was 201.1 LPM (SD: 26.3) for twenty-four healthy undergraduate males of mean age 20.2 years (SD: 1.0). This minute volume was achieved at a mean breathing rate of 146.0 BPM (SD: 26.0), recorded for three trials, Session #2.

2. Mean vital capacity was 5.46 litres (SD: 0.69) for seventy-two healthy undergraduate males of mean age 20.4 years (SD: 1.42).

3. Significant correlations for the same respective groups were: a) height with MVV: 0.47 ($0.05 > P > 0.02$); b) height with vital capacity: 0.67 ($P < 0.001$); c) weight with vital capacity: 0.33 ($P < 0.01$); and d) surface area with vital capacity: 0.49 ($P < 0.001$).

A. Hypotheses Inferred as Being Supported by the Results of the Present Study.

The following hypotheses were inferred as being supported by the results of the present study:

1. The directive, "Breathe as deeply and as quickly as you can!" is no more effective in achieving optimal minute volumes than the directive, "Get as much air into that (Douglas) bag as you can!" (Mean MVVs significantly different at $\alpha = 0.05$.)

2. A subject caused to breathe faster than at a freely elected rate more closely approaches an optimal value of MVV ($P < 0.05$, Sessions #1:2; 1:3).

3. An intersession practice effect is peculiar to a series of MVV test sessions ($P < 0.05$, Sessions #1:2; 1:3).

4. The mean optimal rate of breathing for the test of MVV is in excess of 100 BPM.

5. The largest MVV recorded during a test session is no more valid an indication of that parameter than is the mean of three trials.

B. Hypotheses Inferred as Being Unsupported by the Results of the Present Study.

In regard to those hypotheses inferred as being unsupported by the results of the present study:

1. Only limited and opposing inference could be drawn in respect to the hypothesis that a subject does not intuitively choose a breathing rate that provides optimal MVV.

2. Similarly, inferences drawn were contrary to the hypothesis that subjects with greater vital capacities achieve largest MVVs at faster breathing rates than those with smaller vital capacities.

3. The hypothesis that nonsmokers demonstrate superior performance in tests of vital capacity and MVV was inferred as being unsupported by the results in respect to vital capacity only. Limitations of experimental design prevented the MVV aspect of the hypothesis from being investigated.

Conclusions and Recommendations

A. Suggested Modification of the Test of Maximal Voluntary Ventilation For Administration to Adult Males Approximately Twenty Years of Age, With No Evidence of Pulmonary or Cardiac Disease, or Breathing Obstruction.

1. Retain the directive, "Breathe as deeply and as quickly as you can!" although it might be supplemented with, "Get as much air into that (Douglas) bag as you can!" to ensure that the subject has a clear understanding of the nature of the performance that is required of him.

2. Provide for the effect of practice by administering two test sessions of three trials each (alternate-day sessions would appear suitable).

3. Calculate the mean of three trials, Session #2, and observe this as the measure of the subject's ability. (The best score of three trials is apparently as reliable, from session to session, but as an extreme value is not as representative.)

4. Demonstrate to metronome prior to Trial #1 each session, but do not draw attention to the rate of this performance. (One hundred BPM was the rate employed in this study, but there are indications (see Table IV:13) that it should be 120 BPM or faster.) Be sure that the demonstration is forceful.

5. Record the breathing rate for each trial. If the subject's mean rate, Session #2, is not within the range 146 $\pm$ 26.0 BPM, achieved Session #2 in the present study by combined Groups 1B and 2A, conduct a third alternate-day test session, and direct the subject to perform within the range of suggested breathing rates. Demonstrate to

metronome at 146 BPM to achieve this purpose. If the mean of three trials indicates as being larger than for Session #2, accept this value.

B. Recommendations For Further Research

Subjects for research which derive from the present study are as follows:

1. Free-rate MVV at faster breathing rates for healthy unobstructed subjects, to explore the possibility that their optimal MVV breathing rates may range to perhaps 180 BPM. (The best mean volume for a session in the present study was achieved at mean rate 141 BPM (SD: 15.0) by Group 1B, Session #3).

2. Clinical investigation in regard to a standardized rate of demonstration to metronome.

3. The effect of obesity upon MVV. There were performance indications in this study that obesity is a significant factor in the MVV-weight correlation.

4. Repetition of the study by Stuart and Collings (38) who sought to differentiate between the MVV scores of conditioned athletes and sedentary subjects. Modification of the test of MVV as suggested in the present study, might be considered.

5. Further to the above, a determination for healthy unobstructed subjects of whether the test of MVV effectively differentiates between divergent levels of CV-R fitness, the suggested criteria for the latter being a work capacity test.

6. Separate normative studies of healthy unobstructed males and females for selected age groups.

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APPENDICES

APPENDIX A

WEDGE SPIROMETER CALIBRATION

Calibration of the Wedge Spirometer

Prior to the test period the Wedge Spirometer was calibrated as follows:

Room air was discharged into the spirometer in 200cc increments from a standard surgical syringe. Increases in volume were observed to be substantially linear. In addition, accumulated volumes corresponded accurately with those indicated by the calibration output of the Electronics for Medicine (E for M) recorder.

APPENDIX B

SUBJECT INSTRUCTION

MVV Instruction Given to all Subjects

The standardized instruction given to all subjects was as follows:

1. Each of the three sessions that you spend in the laboratory you will perform three twelve-second breathing trials, with recovery periods of 3-5 minutes between.

2. This is the mouthpiece and the valve* that you will breathe through.

3. Each trial will be timed on the clock which is marked so that the first available quarter convenient to both of us can be used.** Observe the following procedures:

a) Insert the mouthpiece on the 'one', 'four', 'seven' or 'ten' numeral on the clock.

b) Relax for what remains of the eight-second period until the red marker, breathing normally through the nose.

c) Position the tongue lightly across the entrance to the mouthpiece to ensure nasal breathing prior to the commencement of the trial, and to prevent building up pressure between the Triple-J valve and the valve regulator at this time.

d) Make final preparations during the countdown. The red

---

*The subject was handed these items, and with identical equipment the technician demonstrated how to: (1) fit the mouthpiece; (2) seal the nostrils with thumb and forefinger; and (3) breathe normally through the mouth. These procedures were practised by the subject.

**The technician demonstrated test procedure, removing the mouthpiece from time to time to issue self-instruction.

marker indicates the commencement of a 'Three! Two! One!' countdown following the eight-second period of preparation and relaxation. Continue to breathe relaxedly through the nose during the countdown until the signal, "Go!" Have the forefinger and thumb of the free hand up to the face ready to seal the nostrils on this command. When it is given, simultaneously seal the nostrils, draw the tongue from the entrance to the mouthpiece, and begin maximal breathing. Remember that you will be breathing through your mouth and consequently the J-valve, which admits room air.

e) Towards the end of the twelve-second trial you will probably experience some faintness due to overbreathing. Don't decrease your efforts; continue to do your absolute best. You will recover quickly after each trial, and not experience any after-effects.

The technician demonstrated an actual start, to reinforce the subject's comprehension of procedures and synchronization. The subject practised a start, briefly and passively.

A resume of procedures was given prior to Trial #1, Day #2 and #3. A vigorous demonstration of a treatment condition was always given before the subject performed Trial #1 of free-rate MVV, or before any trial at a different prescribed rate during a test session.

If the condition involved free-rate respiration the demonstration was standardized by the technician performing to a metronome set at 100 BPM. Alternatively, if the condition required that a certain prescribed rate of respiration be effected, an electric metronome was used (see page 39). The instructions for such a trial were

few and self-evident.

Prior to and during each test trial the subject was instructed to, "Get as much air in that (Douglas) bag as you can!" (GMABC!") or alternatively to, "Breathe as deeply and as quickly as you can!" (D&Q!"). Whenever the former instruction was given, care was taken to direct the subject's attention to the Douglas bag.

APPENDIX C

GAS METER VOLUME CORRECTION

Gas Meter Volume Correction

The American Meter Company gas meter (model 802) was tested in reference to a Collins 120-litre chain-compensated gasometer accepted as standard. From a regression analysis of collected data the equation $Y = .9934\ X + .1540$ was obtained. ("Y" represents the corrected ATPS volume, and "X" the volume indicated on the meter.) Subsequently, ATPS volumes were corrected from tables constructed according to the above formula. The reliability of the correlation coefficient was calculated as being near-perfect.

APPENDIX D

GAS VOLUME CONVERSION

<u>Conversion of Vital Capacity Volume from ATPS to STPD</u>

Each vital capacity score obtained from the Electronics for Medicine recorder, being an ATPS volume, was converted to STPD. This change was achieved by multiplying the score times the appropriate conversion factor read from a table constructed according to the formula: $(P_B - P_{H_2O}) / 760(1 + 0.00367T)$. ("$P_B$" represents the ambient barometric pressure; "P_{H_2O}", the vapour tension of water in mm Hg, at the temperature of the spirometer; and "T", the temperature of the spirometer in ^{o}C. Reference was made to Consolazio *et al.* (11:6) for the formula).

<u>Conversion of Vital Capacity Volume from STPD to BTPS</u>

The expression of vital capacity at BTPS is customary in the literature therefore each STPD volume was multiplied by the appropriate factor from a table constructed according to the formula (11:196): factor = $.83/(P_B - 47)$. (Both temperature and pressure components of this factor augment the STPD volume in the change to BTPS, in that: (1) gas temperature is increased from 273 to 310^{o} Absolute (body temperature); and (2) standard barometric pressure (760 mm Hg) is reduced to ambient pressure and adjusted for saturation with water vapour at body temperature. Hence the "47" (mm Hg) indicated in the formula.)

<u>Conversion of Raw Score MVV to BTPS Minute Volume</u>

Raw score MVV was converted to BTPS minute volume as follows:

1. The raw score was corrected for gas meter error (see Appendix C).

2. Corrected MVV (ATPS) was converted to STPD in the same manner as was vital capacity (see Appendix D).

3. The MVV (STPD), expressed to this point as a twelve-second volume, was converted to a BTPS minute volume by multiplying the value by times five the appropriate factor selected from the table referred to in Appendix D.

APPENDIX E

THE DETERMINATION OF BODY SURFACE AREA

The Determination of Body Surface Area

The prediction formula of Du Bois and Du Bois (15), was used to calculate body surface area. The formula is: BSA = 0.007184 X Height $^{0.725}$ X Weight $^{0.425}$ metre^2. Calculations were checked for sizeable error by reference to the nomogram provided by the authors.

APPENDIX F

RECORDED DATA*

* Gas volumes corrected and converted to BTPS

KEY TO CLASSIFICATION OF DATA*

I. GENERAL DATA

Groups IA-3B

Subject number	1
Smoker: "1"; nonsmoker: "2"	2
Subjective rating of:	
a. Level of physical activity (high: "1"; moderate: "2"; and low: "3")	3
b. Musculature (superior: "1"; medium: "2"; and slight: "3")	4
c. Body weight (obese: "1"; medium: "2"; and underweight: "3")	5
Age (years)	6
Height (cm)	7
Weight (kg)	8
Surface area (m^2)	9

II. VITAL CAPACITY

Trial #1	Trial #2	Trial #3	Best of 3	Mean of 3
10	11	12	13	14

III. MVVs AND BREATHING RATES

Day		#1	#2	#3	Best of 3	Mean of 3
#1	MVV	15	16	17	18	19
	BR	30	31	32	33	34
#2	MVV	20	21	22	23	24
	BR	35	36	37	38	39
#3	MVV	25	26	27	28	29
	BR	40	41	42	43	44

Group 2B

(As for "1", plus (1) ordered MVVs at attempted 112, 148 and 184 BPM, Sessions #2 and #3; and (2) ordered actual rates of breathing.)

Day	Attempted Rate	MVV	Actual Rate
#2	112	45	51
	148	46	52
	184	47	53
#3	112	48	54
	148	49	55
	184	50	56

Groups 3A and B

(As for "1", plus (1) ordered MVVs at attempted 76, 112 and 148 BPM, Sessions #1-3; and (2) ordered actual rates.)

Day	Attempted Rate	MVV	Actual Rate
#1	76	57	66
	112	58	67
	148	59	68
#2	76	60	69
	112	61	70
	148	62	71
#3	76	63	72
	112	64	73
	148	65	74

*Numbers identify fields of data. Fields 6-8: one decimal place; fields 9-74: two decimal places.

012	313	198	1727	660	179	437	457	440	457	445	18636	17836	17719	18636	18064	17818
022	121	194	1740	705	185	495	487	517	517	500	20236	21125	19931	21125	20431	19621
032	322	189	1791	696	187	562	567	582	582	570	18571	18623	17895	18623	18363	21053
042	212	194	1689	637	173	453	487	483	487	474	21092	21581	23833	23833	22169	24677
052	313	199	1778	848	203	488	512	502	512	501	20700	22098	21497	22098	21432	22226
062	212	237	1588	631	165	410	436	438	438	428	17685	18137	18537	18537	18120	19043
072	323	197	1765	721	188	535	574	564	574	558	17988	17751	18381	18381	18040	19638
082	333	198	1829	637	183	549	558	576	576	561	22172	22663	22984	22984	22606	23743
092	313	201	1791	760	195	519	500	509	519	509	20744	20063	18595	20744	19801	19083
102	323	198	1791	694	187	474	467	464	474	468	17535	18972	20762	20762	19090	21747
112	322	213	1727	662	179	522	505	518	522	515	16774	17896	17555	17896	17408	19427
121	212	189	1803	787	198	660	641	672	672	658	19920	20229	19631	20229	19927	21126
132	222	197	1816	755	196	561	573	567	573	567	22358	21618	21216	22358	21731	23670
141	323	204	1727	615	173	582	582	573	582	579	17620	18302	19243	19243	18388	18547
152	322	197	1803	671	185	504	507	499	507	503	18018	17238	16920	18018	17392	18597
162	322	198	1740	737	188	625	632	630	632	629	19934	21691	22394	22394	21340	22744
172	332	196	1753	705	186	541	562	583	583	562	17200	19912	19178	19912	18763	22494
182	322	227	1791	785	197	689	691	689	691	690	22343	23150	25938	25938	23810	25092
192	223	207	1791	658	183	548	549	551	551	549	19044	18316	18991	19044	18784	18270
201	322	208	1715	719	184	537	568	551	568	552	20106	19969	19595	20106	19890	20868
212	312	190	17 7	578	169	504	547	535	547	529	22494	21891	21805	22494	22063	22659
222	222	199	1715	699	182	449	489	491	491	476	19920	21707	19979	21707	20535	20098
232	223	233	1816	755	196	562	576	556	576	565	13652	15834	16648	16648	15378	17238
242	212	198	1727	606	172	504	503	512	512	506	19608	20349	21300	21300	20419	20178
12	345	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CODE NUMBERS

DATA FOR GROUPS 1A (01-12) AND 1B (13-24)

01	17440	17440	17818	17566	16745	17689	18587	18587	17674	110	124	115	110	116
02	19439	19361	19621	19474	19125	19265	18573	19265	18988	093	095	100	095	096
03	21444	21601	21601	21366	22915	22702	22994	22994	22870	113	125	114	125	117
04	24370	23632	24677	24226	24190	24123	23632	24190	23982	114	126	130	130	123
05	21261	20367	22226	21285	20866	16980	16603	20866	18150	120	130	125	130	125
06	20147	20392	20392	19861	19982	21661	20815	21661	20819	078	085	085	085	083
07	18323	18858	19638	18940	18794	18512	17056	18794	18121	088	093	098	098	093
08	22309	22904	23743	22985	23983	23229	23419	23983	23544	083	085	085	085	084
09	17417	18594	19083	18365	19450	18768	18486	19450	18901	121	136	151	121	136
10	19973	21356	21747	21025	20907	20716	18794	20907	20139	119	125	129	129	124
11	20108	20617	20617	20051	21438	20854	20382	21438	20891	120	125	133	125	126
12	20293	19995	21126	S 471	19601	19660	17843	19660	19035	110	130	150	130	130
13	22303	23273	23670	23082	23189	23315	23268	23315	23257	110	110	109	110	110
14	20168	19641	20168	19452	20602	19391	18394	20602	19462	108	113	113	113	111
15	18826	18591	18826	18671	19535	19183	19654	19654	19457	153	175	173	153	167
16	24285	22293	24285	23107	23941	22151	21057	23941	22383	108	115	128	128	117
17	22943	21648	22943	22362	18347	19853	19978	19978	19393	109	112	115	112	112
18	24946	25316	25316	25118	26089	26286	26700	26700	26358	125	130	138	138	131
19	17642	19466	19466	18459	19372	19490	19608	19608	19490	100	109	116	100	108
20	20048	19559	20868	20158	20690	19457	19352	20690	19833	126	120	120	126	122
21	21912	21833	22659	22135	21149	20789	20821	21149	20920	121	141	158	121	140
22	18576	20946	20946	19873	22350	23301	23183	23301	22945	155	183	193	183	177
23	17126	16974	17238	17113	16400	17017	16853	17017	16757	093	114	124	124	110
24	20469	19052	20469	19900	20716	21379	21136	21379	21077	200	125	113	113	146
1	21	22	23	24	25	26	27	28	29	30	31	32	33	34

CODE NUMBERS

DATA FOR GROUPS 1A (01-12) AND 1B (13-24) CONT'NUED

01	121	124	129	121	125	131	133	130	130	131
02	099	104	108	099	104	098	095	103	095	099
03	125	120	129	129	125	140	128	125	125	131
04	148	160	161	148	156	160	168	171	160	166
05	153	154	156	153	154	168	165	168	168	167
06	094	090	091	091	092	096	098	095	098	096
07	108	098	118	108	108	120	120	120	120	120
08	109	103	109	109	107	113	120	123	113	119
09	183	189	188	183	187	180	175	170	180	175
10	160	155	158	160	158	141	147	175	141	154
11	123	130	135	135	129	147	153	143	147	148
12	168	163	160	168	164	200	140	208	140	183
13	118	123	125	118	122	124	121	125	121	123
14	119	119	133	119	124	143	133	116	143	131
15	135	155	160	155	150	148	163	171	171	161
16	134	151	153	151	146	138	144	150	138	144
17	123	115	128	115	122	123	126	126	126	125
18	145	151	163	163	153	150	145	151	151	149
19	111	125	125	125	120	130	135	135	135	133
20	151	180	170	151	167	154	170	158	154	161
21	129	139	155	129	141	121	135	153	121	136
22	206	215	220	220	214	128	141	153	141	141
23	120	120	130	120	123	125	125	125	125	125
24	155	128	149	128	144	135	165	185	165	162
1	35	36	37	38	39	40	41	42	43	44

CODE NUMBERS

DATA FOR 1A (1-12) AND 1B (13-24) CONTINUED

252	121	200	1816	751	196	588	591	605	605	595	20318	20332	20093	20332	20248	19882
262	323	198	1740	767	191	474	485	496	496	485	19457	18128	20240	20240	19275	20868
271	313	195	1664	907	209	401	394	411	411	402	12864	13140	10564	13140	12189	14803
281	333	206	1778	542	168	444	457	434	457	445	16796	17093	16710	17093	16866	20929
292	322	202	1778	746	192	599	599	601	599	600	18025	18131	19083	19083	18413	18741
302	221	197	1842	737	196	562	577	607	607	582	20135	22383	23563	23563	22027	26457
312	222	198	1765	792	196	624	634	614	634	624	17979	19299	20020	20020	19099	18807
321	333	204	1791	599	176	631	656	668	668	652	18004	19058	17865	19058	18309	19080
331	333	208	1816	615	180	614	616	613	616	614	20831	18294	21846	21846	20324	19522
342	322	192	1588	508	148	449	453	468	468	457	14454	13372	13913	14454	13913	16258
352	313	207	1773	814	199	500	494	507	507	500	14982	16744	16837	16837	16188	18080
362	222	192	1791	780	197	497	504	509	509	503	17134	19381	20923	20923	19146	21386
372	313	199	1715	782	191	501	511	514	514	509	16956	18057	20607	20607	18540	21464
382	232	201	1842	696	191	691	709	708	709	703	20640	20172	21286	21286	20699	22249
391	232	209	1778	662	183	532	534	531	534	532	20394	21199	21879	21879	21157	18861
401	312	230	1778	751	193	504	511	518	518	511	15176	16217	16058	16217	15817	16515
412	333	220	1740	621	175	563	535	533	563	544	16912	17583	16912	17583	17136	16229
422	222	190	1791	708	189	601	629	626	629	619	16482	14715	14722	16482	15306	21831
432	222	187	1829	769	199	577	628	616	628	607	20044	18678	18718	20044	19147	21432
441	222	192	1715	669	179	471	500	517	517	496	12479	13339	13253	13339	13024	14725
452	333	196	1740	615	174	481	471	485	485	479	17490	18988	18869	18988	18449	19664
462	111	203	1816	798	201	577	557	587	587	574	17928	18551	18637	18637	18372	17265
472	312	194	1842	807	204	543	544	562	562	550	15909	20478	22702	22702	19696	21704
482	313	199	1727	798	194	485	469	487	487	480	19316	21036	20438	21036	20263	20105
12	345	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CODE NUMBERS

DATA FOR GROUPS 2A (25-36) AND 2B (37-48)

25	19537	19218	19882	19546	18582	19615	20012	20012	19403	135	165	166	165	155
26	19938	20737	20868	20514	19641	18944	20286	20286	19624	121	110	119	119	117
27	13211	14705	14803	14240	15078	14814	15750	15750	15214	205	151	212	151	189
28	20570	19394	20929	20298	20198	18564	18992	20198	19251	113	128	130	128	124
29	18735	18781	18781	18752	19473	18907	19177	19473	19186	075	090	109	109	091
30	26294	23696	26457	25482	25661	26037	25265	26037	25654	066	093	091	091	083
31	21411	20930	21411	20383	22516	22470	22437	22516	22474	114	125	129	129	123
32	18392	18340	19080	18604	18749	18399	17187	18749	18112	136	170	135	170	147
33	20882	22086	22086	20830	19269	18333	19625	19625	19076	095	110	106	106	104
34	14610	16690	16690	15853	15856	15717	16251	16251	15941	138	135	158	138	144
35	18034	17530	18080	17881	16718	15701	15228	16718	15882	178	195	156	156	176
36	19958	21111	21386	20818	20653	20436	19612	20653	20234	119	124	150	150	131
37	20555	16886	21464	19635	16798	19711	18702	19711	18404	155	168	163	163	162
38	16769	15016	22249	18011	17925	15961	18722	18722	17536	095	113	113	113	107
39	21451	18685	21451	19666	22544	18630	21134	22544	20769	134	125	130	130	130
40	14605	15928	16515	15683	17107	16201	15712	17107	16340	119	162	180	162	154
41	16197	16874	16874	16433	16016	17635	17695	17695	17115	125	153	176	153	151
42	21405	21026	21831	21421	20185	21655	21595	21655	21145	104	103	103	104	103
43	22118	19823	22118	21124	20429	21187	19579	21187	20398	098	079	080	098	086
44	13981	13981	14725	14229	15981	15368	15315	15981	15555	149	147	188	147	162
45	19560	16985	19664	18736	18924	16598	17041	18924	17521	130	144	143	144	139
46	16262	15969	17265	16499	16421	16982	16434	16982	16612	110	143	134	134	129
47	21496	22271	22271	21824	21007	21516	19744	21516	20756	124	148	163	163	145
48	20670	21437	21437	20737	22124	20443	20979	22124	21182	121	118	108	118	116
1	21	22	23	24	25	26	27	28	29	30	31	32	33	34

CODE NUMBERS

DATA FOR GROUPS 2A (25-36) AND 2B (37-48) CONTINUED

25	150	149	210	150	170	213	181	199	199	198						
26	126	125	135	126	129	146	148	158	158	151						
27	176	173	193	176	181	190	188	195	195	191						
28	140	130	140	140	137	140	140	138	140	139						
29	123	130	143	143	132	140	153	144	140	146						
30	115	120	121	115	119	115	123	124	123	121						
31	145	135	145	135	142	141	151	155	141	149						
32	205	203	203	205	204	188	200	210	188	199						
33	130	133	109	109	124	130	130	125	125	128						
34	150	143	146	146	146	144	160	180	180	161						
35	145	125	118	145	129	103	138	133	103	125						
36	156	163	173	156	164	145	158	170	145	158						
37	168	185	153	168	169	130	185	153	185	156	16886	21464	20555	16798	18702	19711
38	173	155	163	173	164	185	147	114	114	149	16769	15016	22249	18722	15961	17925
39	118	195	158	195	157	190	131	179	190	167	18861	18685	21451	18630	21134	22544
40	150	188	111	150	150	116	163	188	116	156	15928	16515	14605	17107	16201	15712
41	110	190	160	160	153	123	115	165	165	134	16229	16874	16157	17635	16016	17695
42	124	153	205	124	161	145	180	113	180	146	21831	21405	21026	21595	20185	21655
43	138	109	170	109	139	113	143	158	143	138	22118	21432	19823	20429	21187	19579
44	199	164	129	199	164	155	193	111	155	153	13981	13981	14725	15315	15981	15368
45	175	143	155	175	158	166	173	128	166	156	19560	16985	19664	17041	18924	16598
46	143	130	160	143	144	175	113	136	113	141	17265	16262	15969	16982	16434	16421
47	145	104	166	166	138	195	143	105	143	148	21496	21704	22271	19744	21516	21007
48	181	145	114	114	147	119	168	143	119	143	21437	20670	20105	22124	20979	20443
1	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

CODE NUMBERS

DATA FOR GROUPS 2A (25-36) AND 2B (37-48) CONTINUED

37	153	168	185	130	153	185
38	155	163	173	114	147	185
39	118	158	195	131	179	190
40	111	150	188	116	163	188
41	110	160	190	115	123	165
42	124	153	205	113	145	180
43	109	138	170	113	143	158
44	129	164	199	111	155	193
45	143	155	175	128	166	173
46	143	130	160	113	136	175
47	104	145	166	105	143	195
48	114	145	181	119	143	168
1	51	52	53	54	55	56

CODE NUMBERS

DATA FOR GROUP 2B CONTINUED

492	221	210	1880	835	210	694	710	743	743	716	15545	19182	21769	21769	18832	19923
502	322	208	1816	823	203	690	704	703	704	699	19075	17121	19753	19753	18650	17861
512	222	198	1867	814	207	651	645	680	680	659	17344	20388	20827	20827	19520	22250
521	312	275	1854	959	220	632	654	676	676	654	21233	19169	18324	21233	19575	21484
532	222	202	18 3	739	193	602	595	591	602	596	18505	18473	18131	18505	18370	20674
541	332	200	1816	773	198	596	587	591	596	591	18262	18850	17894	18850	18335	18333
552	221	198	1816	759	198	593	562	598	598	584	16257	19496	21790	21790	19181	21235
562	222	218	1765	773	194	564	581	589	589	578	16677	14009	13845	16677	14844	19701
572	221	206	1791	708	189	572	556	566	572	565	16775	21257	22918	22918	20317	22042
582	221	217	1702	678	179	576	569	548	576	564	17602	16994	17973	17973	17523	17673
592	322	195	1727	689	182	565	556	570	570	564	16485	22869	22510	22869	20621	22452
602	312	215	1778	889	207	561	561	548	561	557	17499	15654	18234	18234	17129	19069
612	322	182	1829	758	198	526	558	559	559	548	20098	20071	20032	20098	20067	22686
622	131	195	1803	660	184	520	553	550	553	541	17695	21165	23413	23413	20758	22689
632	322	193	1740	585	171	548	526	527	548	534	19574	22983	21346	22983	21301	22341
642	121	213	1702	660	177.	537	523	538	538	533	16397	19251	17959	19251	17869	17105
651	332	230	1842	685	190	514	522	516	522	517	16892	17802	11952	17802	15549	16455
662	221	198	1740	748	189	502	5 8	517	518	512	22909	20249	21265	22909	21474	20311
672	121	204	1676	662	175	520	490	522	522	511	22258	23426	19568	23426	21751	26083
681	212	198	1676	746	184	493	482	499	499	491	16780	13989	17304	17304	16024	17365
692	313	232	1664	832	192	464	472	477	477	471	14683	14200	14754	14754	14546	13279
702	312	203	1664	701	178	464	467	470	470	467	11772	15797	15991	15991	14520	17703
711	323	195	1702	596	169	459	442	454	459	452	13008	16681	13598	16681	14429	16487
722	333	203	1715	522	161	439	447	440	447	442	16293	14790	09056	16293	13380	08950
12	345	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

CODE NUMBERS

DATA FOR GROUPS 3A (49-60) AND 3B (61-72)

49	22534	19219	22534	20559	21932	20422	19927	21932	20760	114	073	138	138	108
50	16643	16477	17861	16994	16321	14084	15829	16321	15411	088	113	144	144	115
51	21161	21181	22250	21531	21854	20676	21027	21854	21186	085	151	109	109	115
52	19234	20400	21484	20373	16555	18827	20233	20233	18553	113	156	079	113	116
53	19605	19470	20674	19916	19608	20546	19029	20546	19728	140	100	063	140	101
54	18942	19700	19700	18992	19513	21613	21190	21613	20772	125	155	066	155	115
55	24963	24280	24963	23493	26429	24193	23998	26429	24873	089	115	135	135	113
56	15884	17618	19701	17734	20476	19209	18859	20476	19515	106	150	123	106	126
57	24056	21353	24056	22484	20801	21790	21660	21790	21417	078	110	135	135	108
58	20270	20041	20270	19328	18563	20685	20685	20685	19978	140	183	068	068	130
59	24034	21510	24034	22665	22861	19479	23438	23438	21926	085	123	149	123	119
60	18205	18509	19069	18594	19367	19432	19055	19432	19285	156	116	079	079	117
61	19652	21859	22686	21399	24666	23773	24469	24666	24303	145	084	110	145	113
62	23082	24301	24301	23357	23684	22710	21130	23684	22508	155	070	120	120	115
63	20725	21366	22341	21477	22456	23060	22764	23060	22760	100	131	073	131	101
64	18441	19303	19303	18283	15936	19234	19566	19566	18245	130	105	086	105	107
65	14656	16703	16703	15938	15016	17977	16615	17977	16536	135	103	060	103	099
66	21633	20950	21633	20965	22142	21722	21276	22142	21713	098	073	133	098	101
67	19105	18682	26083	21290	22698	24324	27244	27244	24755	103	135	079	135	106
68	16038	17120	17120	16841	20008	19831	18158	20008	19332	110	080	136	136	109
69	15386	15291	15386	14652	16503	15325	14329	16503	15386	163	080	114	114	119
70	17364	16240	17703	17102	18912	16405	17863	18912	17727	076	115	149	149	113
71	16540	16606	16606	16544	16479	17010	16780	17010	16756	068	130	114	130	104
72	11565	14634	14634	11716	11718	11796	09511	11796	11008	168	085	100	168	118
1	21	22	23	24	25	26	27	28	29	30	31	32	33	34

CODE NUMBERS

DATA FOR GROUPS 3A (49-60) AND 3B (61-72) CONTINUED

49	075	141	108	141	108	145	119	073	145	112	19182	15545	21769	19923	19219	22534
50	116	141	071	116	109	153	075	113	153	114	19075	17121	19753	16477	17861	16643
51	143	120	079	143	114	111	080	143	111	111	17344	20827	20388	21181	21161	22250
52	148	078	130	148	119	075	109	143	143	109	18324	21233	19169	19234	20400	21484
53	085	063	123	085	090	074	126	115	126	105	18131	18473	18505	19605	20674	19470
54	145	078	120	120	114	059	119	140	119	106	17894	18262	18850	18942	19700	18333
55	115	130	090	130	112	138	094	113	138	115	16257	19496	21790	24280	21235	24963
56	170	141	098	170	136	128	079	151	128	119	16677	13845	14009	17618	15884	19701
57	105	141	080	141	109	143	084	105	084	111	16775	21257	22918	21353	22042	24056
58	175	069	110	069	118	075	113	145	129	111	17973	17602	16994	20270	20041	17673
59	100	151	066	151	106	153	055	115	115	108	16485	22869	22510	21510	22452	24034
60	095	075	125	095	098	075	130	103	130	103	18234	15654	17499	18205	19069	18509
61	088	110	139	088	112	110	129	090	110	110	20071	20032	20098	22686	19652	21859
62	075	106	146	146	109	108	145	086	108	113	21165	23413	17695	22689	23082	24301
63	133	080	115	133	109	078	110	140	110	109	21346	19574	22983	20725	21366	22341
64	105	090	130	130	108	078	120	110	110	103	17959	19251	16397	18441	17105	19303
65	105	068	136	136	103	065	135	090	135	097	11952	17802	16892	14656	16455	16703
66	079	125	101	125	102	133	103	075	133	104	20249	22909	21265	20311	20950	21633
67	140	078	109	140	109	080	108	123	123	104	19568	22258	23426	19105	18682	26083
68	078	141	110	110	110	136	105	079	136	107	13989	16780	17304	17365	17120	16038
69	060	110	146	110	105	108	143	076	108	109	14200	14754	14683	13279	15386	15291
70	110	140	073	110	108	140	080	105	140	108	11772	15797	15991	16240	17703	17364
71	125	118	088	088	110	118	085	145	085	116	13008	13598	16681	16606	16540	16487
72	085	108	171	171	121	110	160	085	160	118	14790	09056	16293	08950	11565	14634
1	35	36	37	38	39	40	41	42	43	44	57	58	59	60	61	62

CODE NUMBERS

DATA FOR GROUPS 3A (49-60) AND 3B (61-72) CONTINUED

49	19927	20422	21932	073	114	138	075	108	141	073	119	145
50	14084	15829	16321	088	113	144	071	116	141	075	113	153
51	20676	21854	21027	085	109	151	079	120	143	080	111	143
52	16555	18872	20233	079	113	156	078	130	148	075	109	143
53	19608	19029	20564	063	100	140	063	085	123	074	115	126
54	19513	21613	21190	066	125	155	078	120	145	059	119	140
55	24193	23998	26429	089	115	135	090	115	130	094	113	138
56	19209	20476	18859	106	123	150	098	141	170	079	128	151
57	21790	21660	20801	078	110	135	080	105	141	084	105	143
58	18563	20685	20685	068	140	183	069	110	175	075	113	145
59	19479	23438	22861	085	123	149	066	100	151	055	115	153
60	19367	19055	19432	079	116	156	075	095	125	075	103	130
61	24469	24666	23773	084	110	145	088	110	139	090	110	129
62	21130	23684	22710	070	120	155	075	106	146	086	108	145
63	22456	23060	22764	073	100	131	080	115	133	078	110	140
64	15936	19566	19234	086	105	130	090	105	130	078	110	120
65	15016	16615	17977	060	103	135	068	105	136	065	090	135
66	21276	21722	22142	073	098	133	079	101	125	075	103	133
67	22698	24324	27244	079	103	135	078	109	140	080	108	123
68	18158	19831	20008	080	110	136	078	110	141	079	105	136
69	14329	16503	15325	080	114	163	060	110	146	076	108	143
70	16405	17863	18912	076	115	149	073	110	140	080	105	140
71	17010	16479	16780	068	114	130	088	118	125	085	118	145
72	09511	11718	11796	085	100	168	085	108	171	085	110	160
1	63	64	65	66	67	68	69	70	71	72	73	74

CODE NUMBERS

DATA FOR GROUPS 3A (49-60) AND 3B (61-72) CONTINUED